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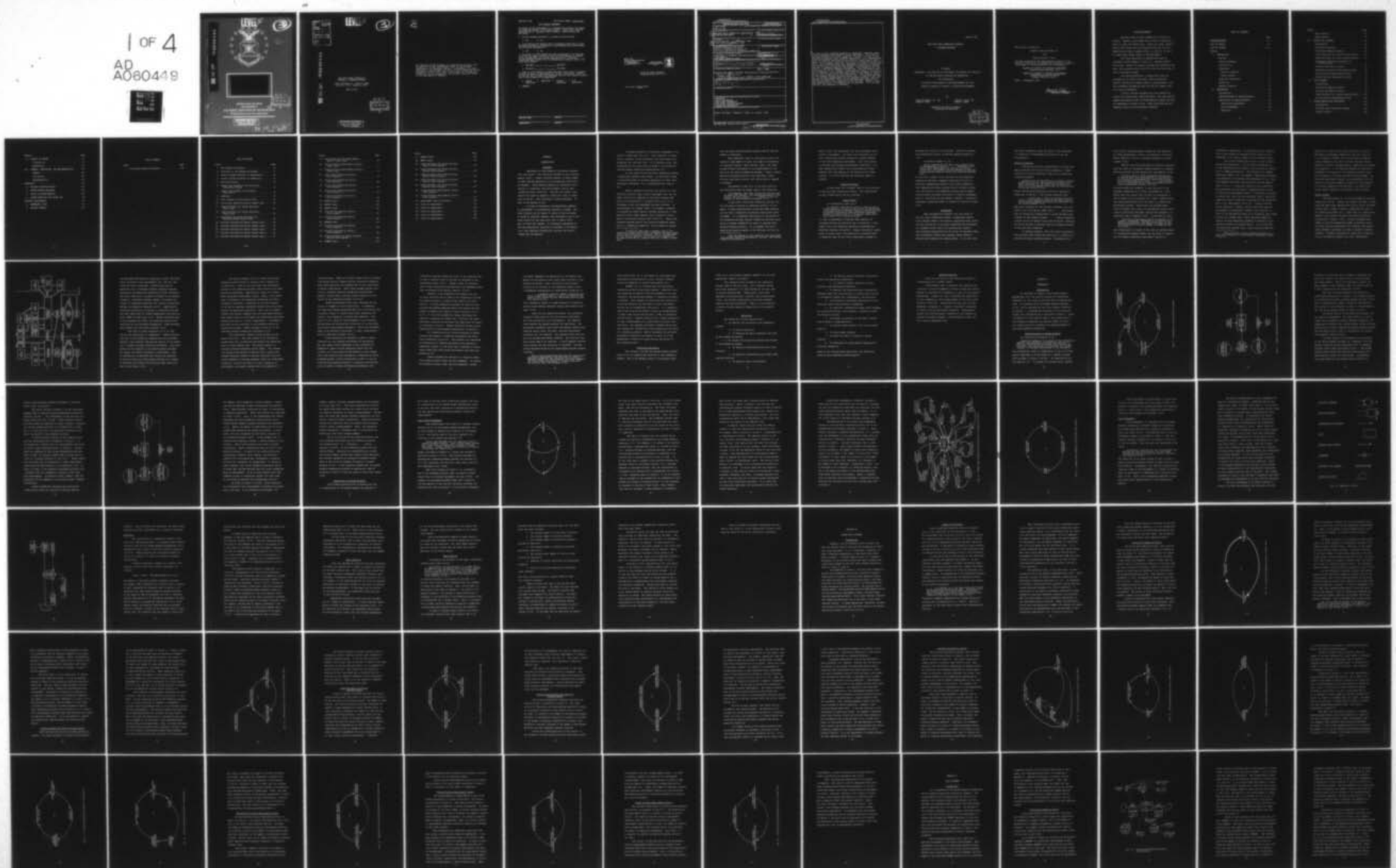

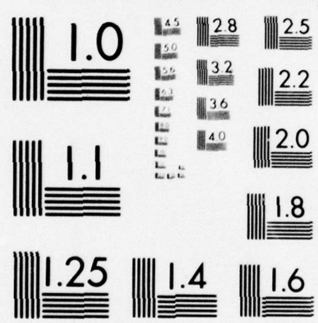
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THE WING LEVEL SCHEDULING
PROCESS: A SYSTEMS APPROACH

Leroy Barnidge, Jr., Captain, USAF
Brian H. Cioli, Captain, USAF

LSSR 15-78B

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In light of the increased emphasis on readiness, realistic capability assessment has become of prime importance. This need for accurate evaluation of true capability, however, has led to one overriding question--what produces capability? It is hypothesized that the decision structure within the wing significantly influences, if not totally controls, the level of capability within that wing. This research effort has undertaken the task of simulating the behavior of a SAC wing-level scheduling organization through the use of computer modeling techniques. The foundation for this effort is the System Dynamics methodology. The realization that a wing operation is in a dynamic, ever-changing state is intuitive. It is, however, quite another matter when one attempts to identify the driving forces within the organization. This elusive nature of the primary factors involved serves only to highlight the need for an accurate understanding of the process involved. Once the process is understood, then a more representative appraisal of the organization's true capabilities can be made. Hence, a more accurate evaluation of readiness can be obtained. It is to this end that this research is devoted.

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THE WING LEVEL SCHEDULING PROCESS:
A SYSTEMS APPROACH

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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and

Captain Brian H. Cioli

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degrees of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(Captain Leroy Barnidge, Jr.)

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(ACQUISITION LOGISTICS MAJOR)
(Captain Brian H. Cioli)

DATE: 8 September 1978

Thomas D. Clark Jr.

COMMITTEE CHAIRMAN

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Men many times envision themselves as being all-capable. Perhaps a self-image such as this is necessary in order to reach the higher goals. There are times, however, when we must stand back and recognize those who are the underlying pillars of support which, in reality, allow us to reach these higher levels of accomplishment.

The first expression of appreciation must be extended to Major Thomas D. Clark, Jr., research advisor and friend. Without his expert guidance and unwavering support, this research effort could not have been concluded in such a successful manner.

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Finally, we must recognize our true reasons for being--our loving wives, Sandy and Sarah. The very special support provided by each of these beautiful people can only be understood in terms of love. Their sacrifice was tremendous; and we will be eternally grateful.

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CHAPTER I

INTRODUCTION

Overview

"Management is the process of converting information into action. The conversion process we call decision making [5:93]." Today's military manager is being tasked to make improved decisions in an increasingly restrictive environment. These decision makers are confronted with a scarcity of resources, declining budgets, and an ever-increasing threat (16:63-67). And yet, the overall task remains the same--to produce a sufficient level of readiness (16:63-67). The challenge is clearly apparent. So what is the manager to do?

In light of Forrester's aforementioned comments, an improvement in informational accuracy is needed. But, such a measure can be costly in terms of time and money. It might be inferred, however, that Forrester's use of the word *information* may imply more than a simple statement of facts and figures. If a manager's perception of how the organization functions is included in the definition, then improved informational accuracy can also be viewed with new meaning.

A primary objective of wing-level management is to ensure a stable work flow (11). This stability is inherently a function of the efficiency with which assets are scheduled into the work flow. In an operating wing, this responsibility for efficiency is found in the operations and maintenance scheduling organizations (11).

In this study of the wing-level scheduling process, a significant question then arises. Do wing-level scheduling personnel have an accurate perception of their total decisional influence? It is hypothesized that they do not.

Today's scheduling officers are placed in a very difficult situation upon initial assignment into the job. These officers are expected to efficiently manage some part of an organization's resources with little or no knowledge of how this management process functions. In the Strategic Air Command (SAC),[1] for example, guidance is provided to these officers through regulations, a numbered Air Force (NAF) seminar, and a minimum of thirty days of on-the-job training (OJT) (14:p.1-1). While this guidance provides much of the technical expertise necessary in a scheduling operation, little insight is gained

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[1]It must be noted that a systemic view of the scheduling process would reveal synonymous insights regardless of the organization observed. Due to the background of the authors, however, the Strategic Air Command will be used to provide all research data and a frame of reference.

into the actual decision-making process used in the management of resources.

Many schedulers learn to efficiently fulfill the technical requirements of their job simply by performing the required actions. These actions, again, are accomplished without the benefit of an understanding of the nature of the overall scheduling process.[2] Hence, without additional personal effort by the individual, these officers could easily evolve into technicians as opposed to managers.

The manager's task (5:1) is far more difficult and challenging than the normal task of the technician.

> In management, many more significant factors must be taken into account. The interrelationships of the factors are more complex. . . . Change is more the essence of the manager's environment [5:1].

In SAC alone, wing level scheduling officers control billions of dollars of resources annually (3:1-2). Hence, it would seem desirable to provide these officers with as firm a foundation as possible toward task accomplishment. If a formalized description of the nature of the scheduling process existed, scheduling officers could build a stronger foundation on which to increase their resource managing ability. It is assumed that such a description would be useful to the officers, not only in

[2]For the purpose of this research, the term scheduling process refers to maintenance, aircraft, and aircrew scheduling collectively.

their initial job orientation, but also throughout their tenure of assignment. To insure this continued utility, such a description should include all related elements in the total scheduling environment. Once this process is outlined and inherent relationships identified, it is then assumed that a model can be developed with which research into the behavior of the system can be accomplished. It is this end that the following study is devoted.

Problem Statement

A need exists for a dynamic model of the structure of the wing level scheduling process. The construction of such a model easily can be justified.

Justification

As indicated by Jones (9:1):

> An aircraft organization exists to provide operational capability in one or more of the following ways: to maintain pilot proficiency through training sorties, to maintain aircraft at peak operational readiness whether on ground alert or in a mission ready condition, and/or to fly actual missions.

In light of Department of Defense (DOD) emphasis on increased savings and efficient use of resources, it has become vital that additional methods be developed for improving resource utilization. Budget constraints, reductions in flying hours, and reductions in personnel make it essential that the Air Force consistently attempt to

maximize the utility of its aircraft. One way to enhance this maximization effort is through improved scheduling (9:1).

As noted by Berman (3:1-2):

> Annual expenditures for SAC flying organizations is approximately $2 billion. . . . Therefore, relatively small improvements in resource allocation efficiency could produce striking amounts of absolute dollars either saved or turned into increased performance.

To this end, a model of the structure of the scheduling process can provide a framework upon which to build an efficient computerized system of wing level scheduling. This computerized system coupled with an accurate insight into the nature of the scheduling process should support efforts toward increased efficiency in resource management. Prior to initiating any new efforts, however, a researcher must make a concerted effort to review all existing information.

Background

When contemplating research into the nature of the wing level scheduling process, a researcher should first consider some of the official responsibilities levied on this activity so as to better understand the philosophical framework within which this process must operate. After becoming acquainted with the nature of assigned tasks, the investigator should then consider recent research efforts which address the subject matter. It is felt that

only after completing these two steps is the researcher in a position to knowledgeably proceed with his own investigation.

Official Viewpoint

The Air Force policy provides much of the philosophical direction for the wing level scheduler. Gibson noted that Air Force Regulation (AFR) 60-12 relates the following guidance:

> Planning for the employment of aircrews, aircraft, guided air missiles, and maintenance resources and their scheduling will be timely and in sufficient detail to insure maximum efficiency and effectiveness in the use of each [6:4-5].

Gibson further noted additional policy for operations schedulers in AFR 60-1. The aircrew scheduler must:

> . . . insure that c. There is equitable distribution of flying hours/sorties/missions among participating aircrew members by controlling individual flying accomplishments [6:5].

Additional guidance for the aircraft scheduler (6:5) was noted in Air Force Manual (AFM) 400-2: ". . . Maintenance must be planned and accomplished to insure optimum effectiveness of such weapons system. . . ." Having completed a brief outline of general policy and direction, attention can now be focused on the more specific guidance provided to the wing level scheduler.

It becomes apparent, after only brief observation, that the wing level scheduling function is a closely controlled and highly governed process. The gudiance for

both aircraft and maintenance scheduling, and indeed for Air Force maintenance in total, is provided in Air Force Manual (AFM) 66-1 which is currently produced in twelve volumes (9:12).

AFM 66-1 was first published in 1958 and indirectly gave the chief of maintenance needed authority to schedule specific aircraft to meet operational requirements (9:14).

> One year later in 1959, the manual was revised to clearly spell out the delegation of responsibility to the chief of maintenance for scheduling aircraft for both maintenance and flying. . . . This responsibility is exercised by the Plans and Scheduling function of Maintenance Control [9:14-15].

Aircraft scheduling, however, is only one part of the assigned responsibility of Plans and Scheduling. This agency must also ensure that aircraft are maintained in such a manner so as to provide for a ready, capable force. This maintenance effort shall be based on a specialized maintenance concept. Specialists are provided under central guidance and control for maintenance actions which require specialized knowledge, specialized equipment, or excessive time to complete (9:12). As detailed by Jones,

> The chief of maintenance staff is responsible for planning, scheduling, assignment of priorities, dispatching of personnel, and controlling work, as well as the selection of skills needed to accomplish the job [9:12].

Once consideration is given to the level of sophistication of a present-day weapons system, one can begin to appreciate the complex scheduling requirements levied on a

maintenance organization. As indicated earlier, however, the aircrew scheduling responsibilities should also be addressed in the initial stages of this research effort.

The aircrew scheduling activity is also a highly controlled organization. One can gain an appreciation of the responsibilities levied on this activity by looking only at command regulations. The Strategic Air Command Regulation (SACR) 50-9, for example, "establishes standardized procedures for planning and programming of all flight crew members/individual crew and flying related requirements [14:p.i]." A detailed reading of this regulation delineates many of the specific responsibilities levied on the mission development branch.[3] This branch is tasked to ensure that each crew and individual flies a sufficient number and types of missions to provide for the accomplishment of all requirements (14:p.1-1). Further scrutiny of the regulation, however, reveals that while specific requirements are addressed, somewhat less attention is given to the methodology required to accomplish these tasks. One may then suppose that a newly assigned scheduling officer has been adequately prepared in advanced to successfully assume the assigned duties. It is noted that the regulation provides that a newly assigned scheduling

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[3]The wing level aircrew scheduling activity is officially referred to as the mission development branch (14:p.1-1).

officer will receive thirty days OJT and will attend a NAF mission development seminar for training (14:p.1-1). It is suspected, however, that the OJT and the seminar concern themselves primarily with the technical aspects required to fulfill assigned duties. Experience reinforces this suspicion. It is therefore assumed that additional knowledge of the nature of the scheduling process could prove helpful to the newly assigned resource manager. As previously mentioned, however, an investigation into the nature of wing level scheduling should not only consider the official aspects of the functions, but should also review similar efforts in the current field of study.

Recent Studies

Two such studies (2; 3) were performed by the Rand Corporation for SAC. Berman, the analyst for Rand, visited three SAC bomb wings, Headquarters 2nd Air Force, and Headquarters SAC in order to obtain a comprehensive view of the scheduling process (2:3). Based upon his observations, Berman's first report portrayed the scheduling process as depicted in Figure 1 (2:6). Berman considered total number of aircraft preparation needs, maintenance crews, and rules and local conventions as variables that maintenance scheduling considers in order to produce a monthly schedule. Variables considered by operations in preparation of the monthly schedule are alert requirements,

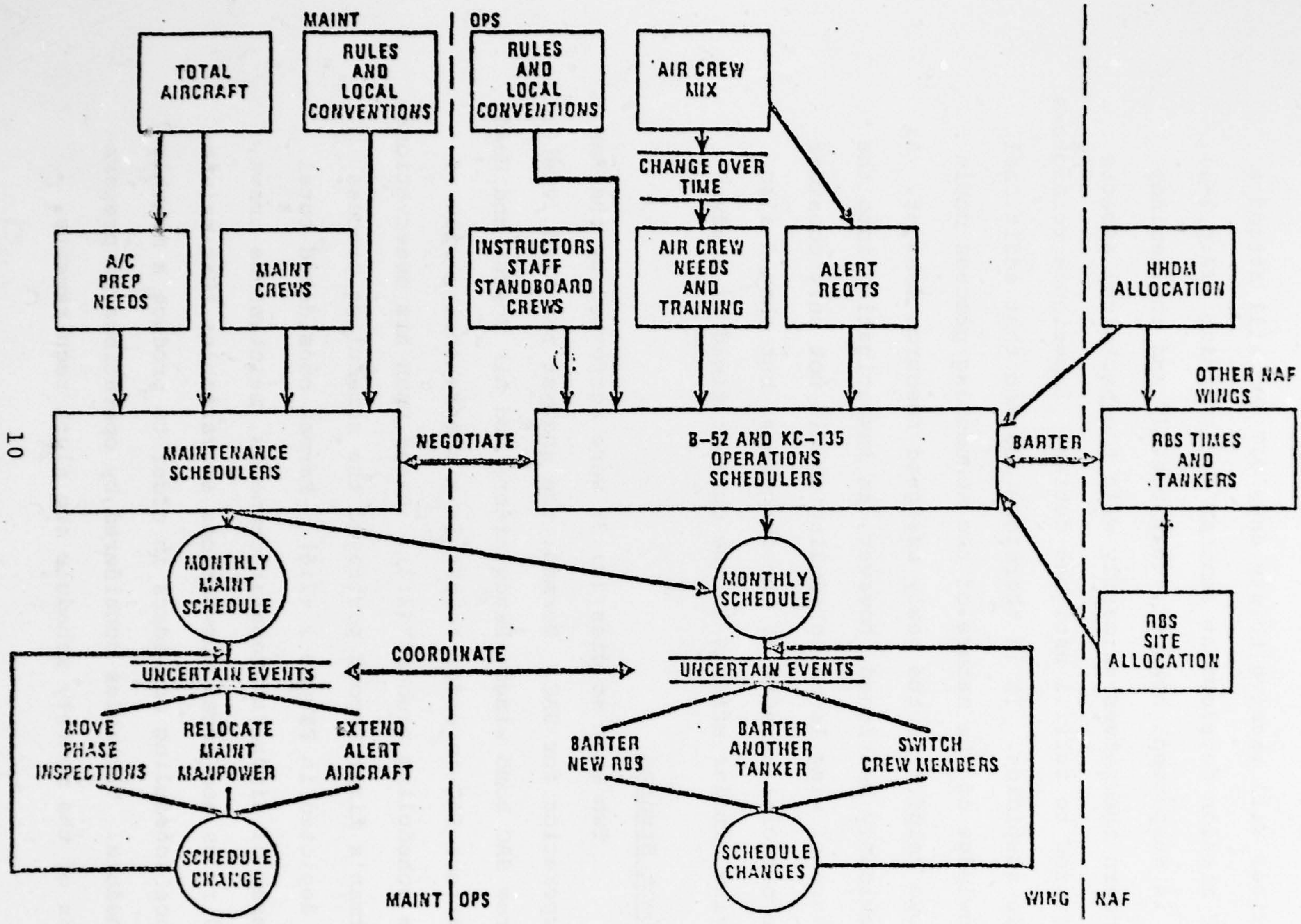

Fig. 1 — The scheduling process [2:6]

aircrew needs and training, instructors, staff, and standboard (evaluator) crew requirements, air crew mix, and rules and local conventions. Negotiations play an important role in developing monthly schedules because maintenance and operations schedulers consider different, and often conflicting, variables as inputs to the monthly schedules. Scheduling changes attempt to overcome the effects of unplanned events and thus require coordination between the scheduling agencies (2:5-7). Additionally, operations scheduling is required to coordinate with NAF and other bomb wings for Higher Headquarters Directed Missions (HHDM) and RBS sites (2:4). Berman noted that many of the problems that affect the scheduling process were identified by the researchers themselves. These problems were grouped into two broad categories (2:8).

The first of these categories (2:vi) is "The quality and limitations of information." Berman observed that most of the scheduling computations were performed manually, thus severely limiting the ability of the scheduler to examine various alternative schedules. Data which would aid the scheduler in the decision-making process are either not readily available or nonexistent. Lack of availability of pertinent data forces the scheduler to plan for short-run effectiveness because he is unable to determine the effects that decisions made today will have in the future (2:vi).

The second category (2:vi) of items that prevent scheduling effectiveness is "Dealing with a complex set of objectives." Many of the objectives that maintenance pursues in the scheduling process often conflict with those pursued by operations. Additionally, there is an inadequate performance measurement system. Hence, little feedback is provided to the schedulers concerning the effectiveness of decisions. Schedulers do not have guidance on the way to negotiate tradeoffs between conflicting maintenance and operations objectives. This lack of guidance coupled with minimal feedback from the performance measurement system create an environment for maintenance-operations negotiations that is, at best, questionable. The benefits and costs are not available to the scheduler during the negotiation process. Berman proposed a solution to the problems affecting scheduling performance (2:vi).

Two interacting, computer-based systems are proposed (2:xii-xiv). The first system is an information system which will provide both maintenance and operations data in a more useable form. The second system is a decision-oriented scheduling system (DOSS). The information system would maintain historical data, display performance measures related to specific decisions thus providing feedback to evaluate progress toward the established objectives, project the effect of future schedules on performance, and prepare reports that are required on a

recurring basis. DOSS will receive inputs from the information system and will examine various alternative schedules which were previously not examined due to the inefficiency of manual computations. While these systems provide solutions to problems affecting scheduling effectiveness, Berman's second report provides further insight into the nature of the scheduling process (3:v-viii).

Berman hypothesized that slack resources are the result of attempts to avoid uncertainty. In comparing two bomb wings, Berman discovered that one of the wings took 30 percent longer to complete postflight inspection and repairs, thus expending 14 percent more manhours. This action (3:vii) resulted "from attempts to gain certainty and decrease the availability of aircraft to fly and hence incur costs in maintenance manpower." While this procedure seems to be obviously inefficient, it does, nevertheless, serve an additional purpose (3:vii).

Slack resources are accepted in order to reduce conflicts not only between maintenance and operations, but also among various subgroups in each organization. Examples of usage of slack resources toward this end include: not flying crews the day before or after ground alert thus reducing crew availability, accepting an easily produced mission (a pilot proficiency flight) in lieu of a more totally productive mission (a complete training mission) in order to reduce pre-mission maintenance, and

scheduling required inspections prior to the required time so that a constant flow of work may be presented to the maintenance docks (3:vii). Berman viewed the extensive use of slack resources as dysfunctional and suggested three ways to minimize this decision behavior (3:vii).

Berman's first suggestion for reducing the use of slack resources was to improve the information provided for decision making in terms of both quality and availability. A second suggestion stressed the need for goal-oriented performance measures which would permit decision makers to observe the effects of their decisions (2:vii-viii). In his third suggestion, Berman reaffirmed the need for a computerized system that "clarifies the cause-and-effect relations of decisions and simplifies the search for solutions [2:viii]." Berman identified several policy implications for the proposed technological innovations.

An interesting policy revision proposed by Berman concerns the thought of combining maintenance and operations scheduling (2:xii-xiv). While Berman only mentioned the possibility of combined maintenance and operations scheduling, Gibson, on the other hand, presented an entire report based upon consolidated maintenance and operations scheduling (6).

Gibson proposed the creation of a separate scheduling agency directly under the Wing Commander. By placing the scheduling agency under the Wing Commander, neither

the Deputy Commander for Operations nor the Deputy Commander for Maintenance would obtain more influence in the scheduling process. Such a structuring would ensure objectivity on the part of the scheduling agency (6:41). A fundamental prerequisite to consolidated scheduling is

> . . . a computer based management information system--a system which must be a whole new approach compared to the old and familiar Maintenance Data Collection System [6:35].

This information system is needed because the scheduling process would undergo extensive change under Gibson's proposal (6:42).

Under the new scheduling process, the operations scheduler would place all of his training requirements and crew availability into the computer. The computer would produce the optimum schedule for operations. The maintenance scheduler would place maintenance capabilities, required launch times, and other important maintenance variables into the computer. The computer would then produce the optimum maintenance schedule. Any conflicts that would arise need to be resolved. A third computer function would analyze the cost and gains of tradeoffs. The new, revised schedule would be the consolidated optimum schedule (6:42-43).

> With a centralized scheduling function using valid performance measurements and supported by adequate computer capability, the schedulers and other managers can follow their performance on a day-to-day basis and evaluate their own progress [6:52].

While both Berman (2; 3) and Gibson (6) considered both maintenance and operations in their research, Hubbard placed his emphasis on aircraft maintenance (8:1).

Hubbard (8:1-2) believed that the maintenance scheduling situation was highly complex. Armed with only the guidelines of AFM 66-1 and the knowledge of his subordinates, the maintenance manager is expected to produce a schedule. This schedule is based upon the availability of men and material and the order in which maintenance actions can be accomplished efficiently. It is Hubbard's thesis that significant benefit toward the accomplishment of these tasks can be derived from a study of precedence network theory. Hubbard asserted that a proper sequencing of task accomplishment will significantly increase total efficiency. The emphasis provided by Hubbard should warrant substantial consideration when studying the structure of a scheduling process. Having considered the available information concerning the subject at hand, it is now appropriate to define the scope and any limitations of this research effort.

Scope and Limitations

This research utilized the System Dynamics methodology (5:13) in studying the structure of the scheduling process. Due to the dynamic nature of the process under

study (6:3), the systems viewpoint seemed to be the most appropriate frame of reference.

This research effort focused on the scheduling process used at the wing level. As a reference system, wing level scheduling in a SAC B-52/KC-135 unit was used to provide research data. Additionally, this study addressed only maintenance, aircraft, and aircrew scheduling. Any further investigation would have exceeded resource and time constraints. Thus, it is now possible to detail the more specific objectives of this research effort.

Objectives

The objectives of this research were:

1. To identify the structure of the scheduling process.

    a. To define scheduling.

    b. To identify the major components that make up the scheduling process.

2. To isolate the interaction between the factors in the scheduling system.

    a. To identify relationships with wing level entities.

    b. To identify relationships with higher headquarters entities.

    c. To identify other relationships.

d. To identify factors relating to both maintenance and operations scheduling.

e. To identify factors unique to aircrew, aircraft, and maintenance scheduling.

3. To identify the cause-and-effect information-feedback loops that link decisions to action which results in information changes and, consequently, new decisions.

4. To formulate an acceptable description of how decisions result from available information.

5. To construct a mathematical model which encompasses identified factors, relationships, information flows, and decision policies.

6. To produce the behavior of the model through time by means of computerization.

7. To contrast model behavior with actual system behavior.

8. To verify model validity.

9. To study the effect of change on system behavior.

10. To understand the requirements necessary for efficient scheduling.

Based on the aforementioned objectives, the underlying question being addressed became apparent.

Research Question

Could the structure of the scheduling process be incorporated into a dynamic model?

A preliminary step in answering this question was to define a suitable framework on which to base this effort. Chapter II provides this framework as a part of the research methodology. Chapter III then illustrates the application of this framework in the accomplishment of the first three research objectives. Objectives four and five are then addressed in Chapter IV. Chapter V provides a discussion of initial results and system validation. Experimental efforts are then discussed in Chapter VI, and Chapter VII provides concluding remarks. The preliminary steps, however, must be addressed first.

CHAPTER II

METHODOLOGY

Introduction

As indicated in Chapter I, the System Dynamics methodology (5:13) was used to provide the theoretical framework for this study of the wing level scheduling process. In accordance with the System Dynamics approach (5:13), and as indicated by the first research objective of Chapter I, a hypothesized structure of the scheduling process was constructed and is depicted in Figure 2. While a discussion of the notation used in the construction of this diagram is deferred, the depicted model can serve as a useful basis for discussing the appropriateness of the System Dynamics methodology.

Appropriateness of System Dynamics

As indicated by Forrester (5:13):

> Industrial dynamics is the study of the information-feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise.

This methodology allows an organization or any of its component subsystems to be portrayed by a feedback process such as shown in Figure 3 (12:242). An organization can be viewed as a control system that defines goals, reaches

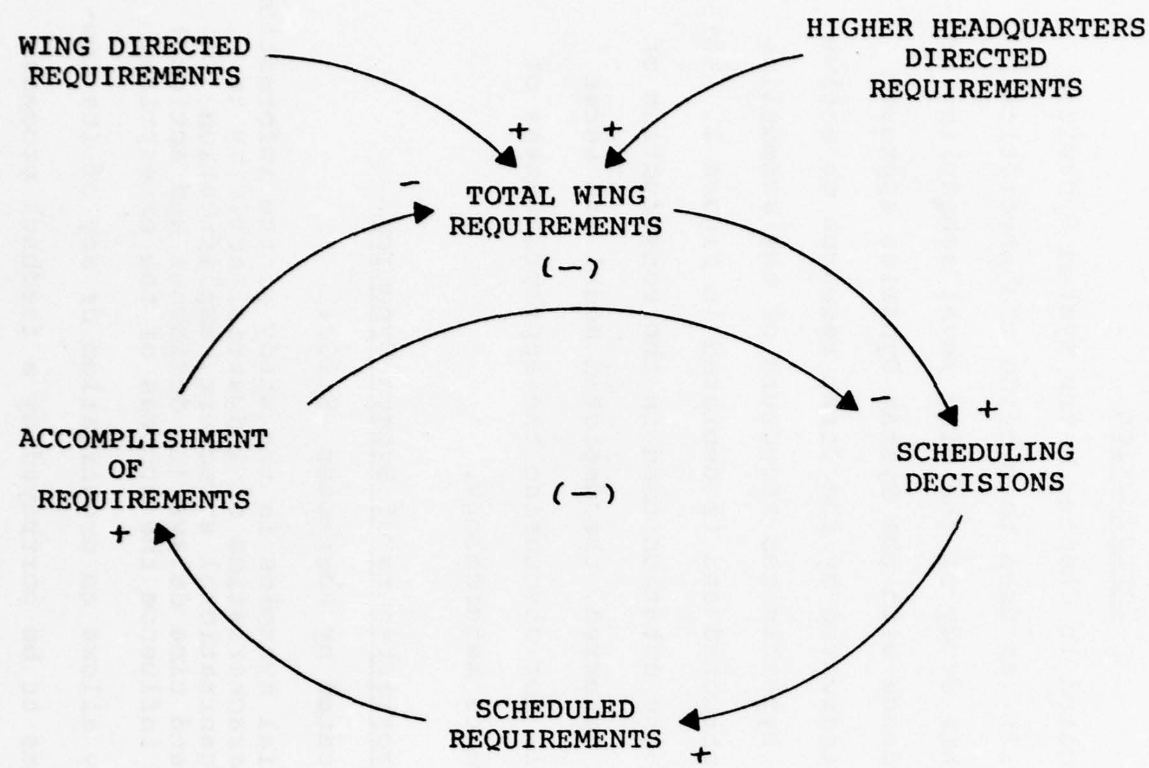

Fig. 2. Structure of the Scheduling Process

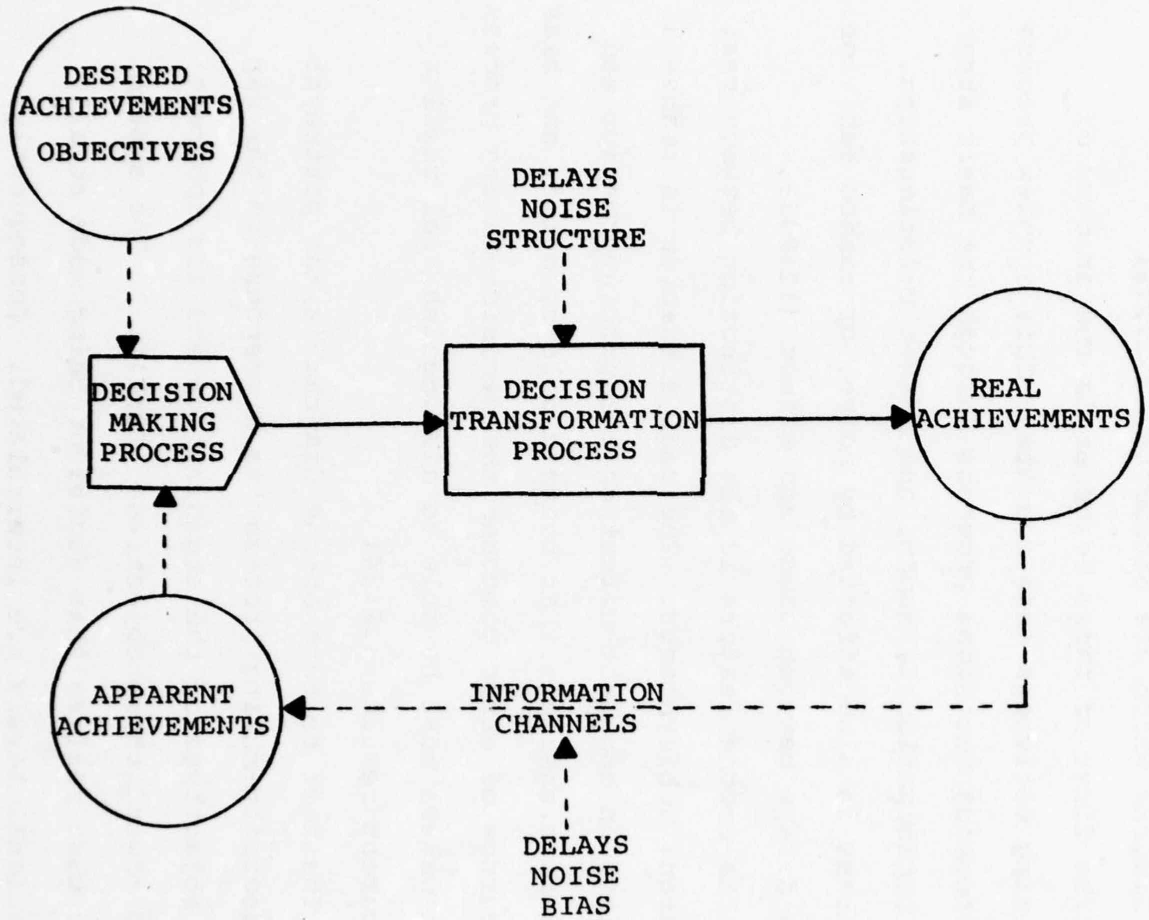

Fig. 3. Control System Structure of Organization [12:242]

decisions to facilitate goal attainment, transforms decisions into results, and adjusts future decisions based upon these results. While this description entails the basic elements of the diagram, there are certain features of this diagram which are noteworthy (12:241).

The first of these features is the process of transforming decisions into results. This complex process of transforming decisions proceeds through the basic structure of organizational, human, and market relationships. This process is also affected by noise, or random behavior, and time delays between cause and effect (12:241).

The second feature is the distinction between real and apparent achievements. The real situation is transformed into an apparent situation through information and communication channels that contain delays, noise, and bias. These sources of error compound the decision-making process. Decision makers must be able to distinguish real results from apparent results (12:241).

The next feature of the diagram is the portrayal of the decision-making process "as a response to the gap between objectives of the organization and its apparent progress toward those objectives [12:241]." The system designer must realize that decisions being made at all organizational levels are interrelated. Consequently, the system designer must develop policies which will

channel these decisions toward achievement of organizational goals (12:241-242).

The fourth feature of Figure 3 "is the continuous feedback path of decision-results-measurement-evaluation-decision [12:242]." The consequences of one decision will always affect the next (12:242). These features coupled with the process as depicted in Figure 3 present a theoretical control system structure of an organization (12:241-242). It was felt that this theoretical structure could easily be applied to the scheduling process.

A control system structure of the scheduling process was constructed and is suggested in Figure 4. It is noteworthy to observe that all relationships identified in Figure 4 were presented earlier in Figure 2. Requirements are generated by both Higher Headquarters and wing staff inorder "to maintain combat-ready aircrews and aircraft as a credible deterrent to war [2:v]." Recent experience indicated that the scheduling of these requirements constituted the major portion of the scheduler's job. As shown in Figure 4, the scheduler transforms decisions into a schedule that will accomplish a portion of the total wing requirements. It should be noted, however, that the production of the schedule is not without several inherent inaccuracies.

Current scheduling techniques may precipitate inefficiencies which are contrary to desired behavior.

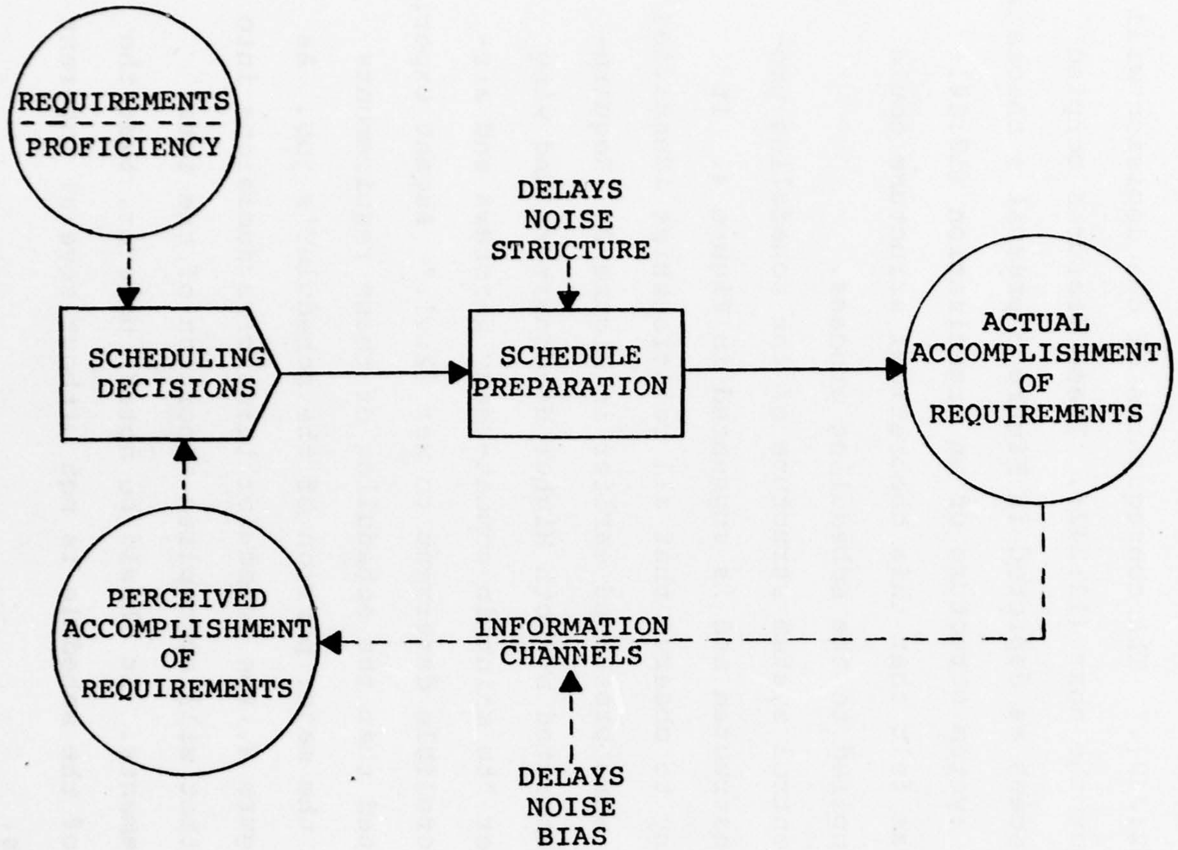

Fig. 4. Control System Structure of Scheduling

For example, while preparing a future schedule, a scheduler may be subjected to many interruptions and distractions. These untimely diversions can lead to inaccuracies in schedule preparation. These inaccuracies are classified as noise (12:241). Also, it was acknowledged that manual techniques and other scheduling inefficiencies led to lengthy delays between schedule conception and production (2:vi). Hence, the effect of these delays had to be considered when analyzing the scheduling process. A third factor that was considered was the actual structure of the scheduling process itself. It was assumed that all organizations inherently exhibit a certain degree of inefficiency. These inefficiencies could lead to further inaccuracies. Hence, consideration must be given to the process structure. In spite of the inefficiencies and inaccuracies caused by noise, delays, and structure a schedule will be produced and, consequently, scheduled activity will ultimately be accomplished. It should be noted, however, that future scheduling decisions cannot be based upon insights derived from the actual accomplishment of requirements. To do so would require real-time feedback as well as subjective insight into such items as true benefits derived from accomplished training.

As noted in Figure 3 (12:242), future decisions are influenced by real achievements as modified by delays, noise, and bias. In the scheduling environment, for

example, reports of actual accomplishments can be delayed up to five days (2:9). This delay combined with continuing inputs from other sources can clearly alter the decision maker's perception of actual accomplishments. Furthermore, the noise that affects schedule preparation can also distort a decision maker's perceptions. These distortions coupled with individual bias can produce varying perceptions of actual accomplishments. Hence, the scheduling officer encounters a formidable task in eliminating the distortions from actual accomplishments.

While this discussion has identified several specific problems associated with the scheduling process, the systemic nature; i.e., "decisions . . . results . . . decisions [12:242]," of the scheduling process has also become evident. Decisions are transformed into actions and actions produce results which affect future decisions. This process represents an information-feedback system which is the first and foremost foundation of System Dynamics (5:14). It was therefore assumed that the System Dynamics methodology provided an appropriate frame of reference in which to study the nature of wing level scheduling.

Application of System Dynamics

The following sections will be devoted not only to a description of how System Dynamics was applied to

this study of the wing level scheduling process, but also to a description of the System Dynamic methodology itself. It was felt that this integration of methodology description and application would provide greater clarity and understanding.

Causal-Loop Diagramming

When investigating the nature of a systemic process through the use of the System Dynamics methodology, one is first tasked to identify the structure of the process (5:13). The vehicle used to initially represent this structure is the causal-loop diagram (7:5).

> Causal-loop diagrams play two important roles in systems dynamics studies. First, during model development, they serve as preliminary sketches of causal hypotheses. Second, causal-loop diagrams can simplify illustration of a model [7:5].

Goodman provided an example of a causal-loop diagram as depicted in Figure 5 (7:10). This diagram portrays the hypothesized interrelationships between job availability in a city, migration into the city, labor force, and current employment level (jobs).

When first looking at figure 5, it is possible, due to the arrowhead notation used, to observe a directional flow of influence throughout the loop (7:5-6). For example, the hypothesized model shows that a change in job availability in the city will directly influence the migration into the city which, in turn directly influences

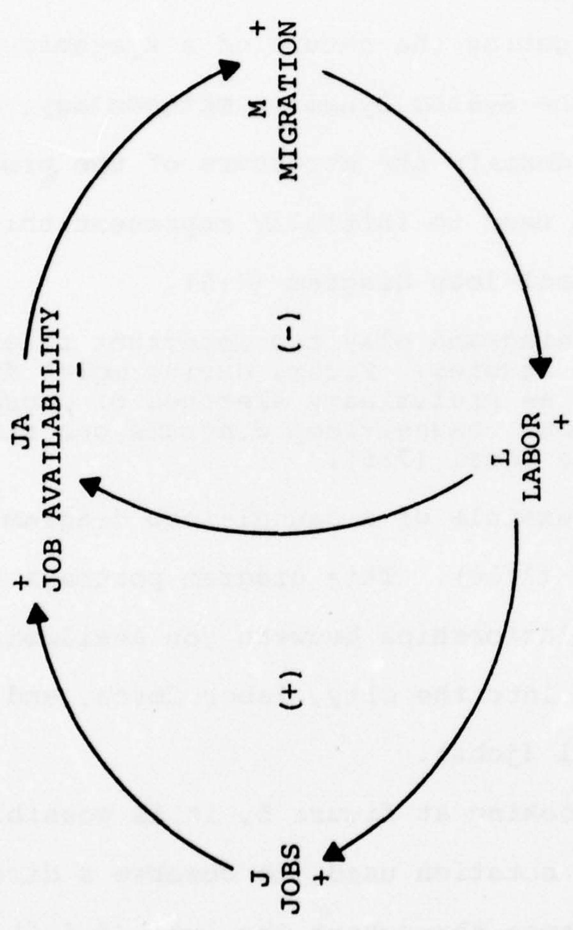

Fig. 5. Two-Loop Diagram [7:10]

the size of the labor force in the city. It can be further noted, that labor directly influences two different variables, jobs and job availability. The final link which completes the cycle is provided by the hypothesized influence that jobs have on job availability. Thus, the cycle is complete and continuous. The arrowhead notation used to indicate directional flow of influence does not, however, provide an indication as to the nature of the influence. Such an indication is provided by the plus (+)/minus (-) symbology.

The type of influence that one variable has on another can easily be represented by the System Dynamics symbology (7:7). For example, if a change in one variable precipitates a corresponding change in a second variable, i.e., increase-increase or decrease-decrease, then the relationship between the variables is considered to be positive and is represented with a plus (+) sign. If, on the other hand, a change in one variable produces the opposite effect in the second variable, i.e., increase-decrease or decrease-increase, then the relationship is considered to be negative and is represented with a minus (-) sign. Referring again to Figure 5, it can be observed that an increase in job availability is considered to also produce an increase in migration which, in turn, produces an increase in the city's labor force. Note, however, that while an increase in labor produces an increase in

jobs filled, this same labor increase serves to decrease jobs available. Hence, a change in one variable can simultaneously produce different effects on other variables. All of these hypothesized relationships can, however, be graphically depicted in a causal-loop diagram. One final consideration which can be represented in the causal-loop diagram is the nature of the complete loop.

A complete causal-loop can either be negative (stable) or positive (continuously reinforcing) (7:9). For example, again referring to Figure 5, a completed loop is represented by JA-M-L. The combined results of the true individual relationships produce a negative (-), or stable, loop. This implies that the total flow through the loop, beginning at JA for instance, would continuously increase if not for the moderating effect of the L-JA relationship. This hypothesized L-JA relationship tends to damp out changes and thus causes the loop to continuously seek a stable, or equilibrium, level. The JA-M-L-J loop, however, is considered to be a continuously reinforcing, or positive, loop. It can be noted that any change in a variable in the loop will tend to be reinforced, or perpetuated, throughout the loop. It becomes apparent that such a loop could grow out of control unless constrained by some other interacting variables. It is noted that the previously described L-JA relationship provides the needed constraint.

Causal-loop diagramming, therefore, provides a means not only for identifying the variables in a process, but also for graphically depicting the individual and combined interrelationships among these variables. It is this necessary first step that provides a basic framework for future efforts in the model-building process (7:5).

The application of the causal-loop diagramming concept to the wing-level scheduling process led to the hypothesized relationships depicted in Figure 6. While Figure 6 portrays a combined representation, it is evident that the development of this presentation began with the construction of individual loops of the type indicated earlier in Figure 5. One such individual loop is presented in Figure 7. This figure presents the hypothesis that an increase in the number of flying hours remaining leads to an increase in the number of flying hours scheduled which, in turn, leads to an increase in the number of flying hours flow, and, therefore, to a decrease in the number of hours remaining. Furthermore, Figure 7 can be observed to be a negative, or stability seeking, loop due to the moderating effect of the hypothesized hours flown-hours remaining relationship. Hence, a complete cycle of variable interrelationships is presented and thus available for inclusion into the total system model such as Figure 6.

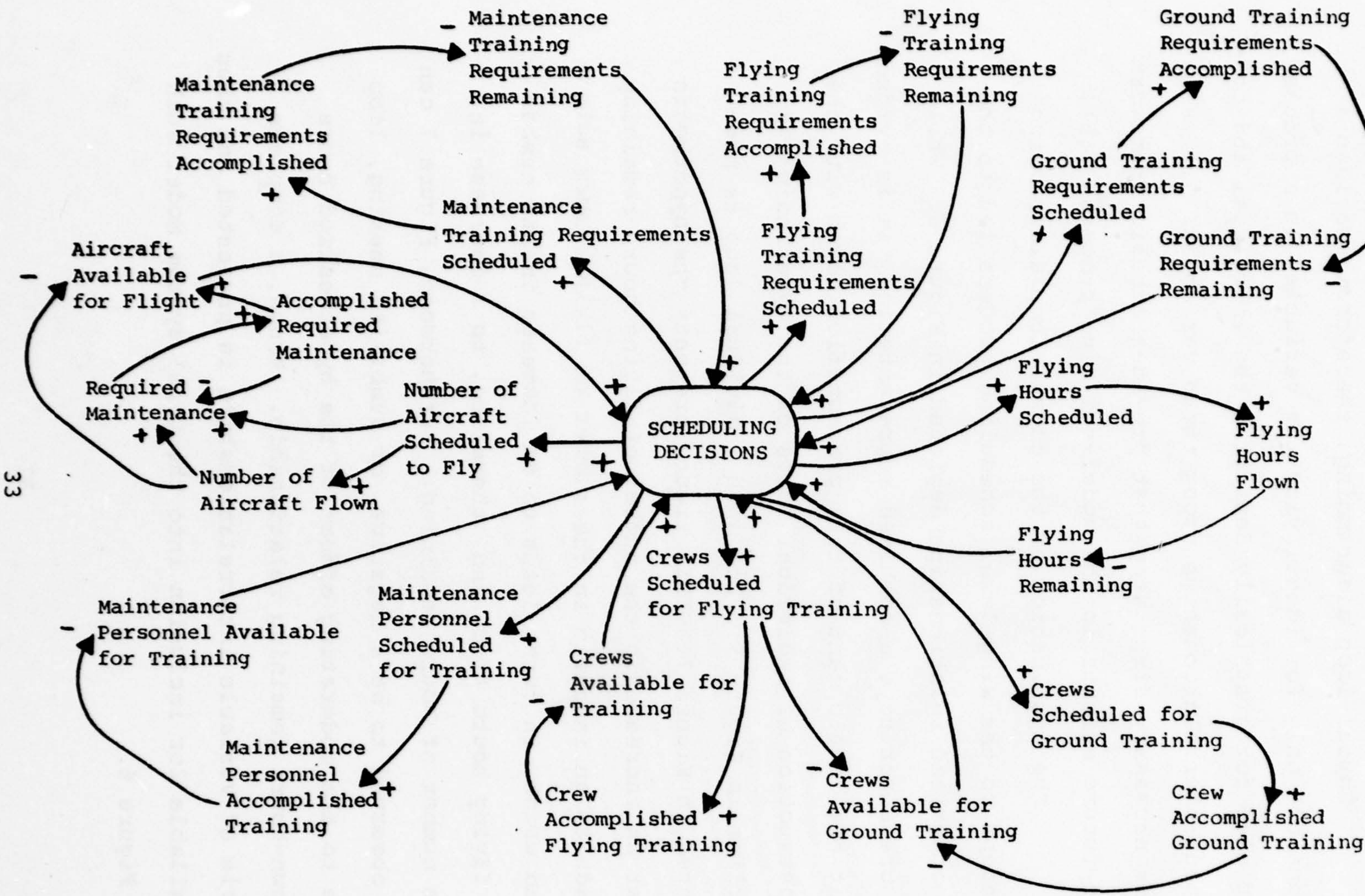

Fig. 6. Causal Loop Diagram of the Wing Level Scheduling Process

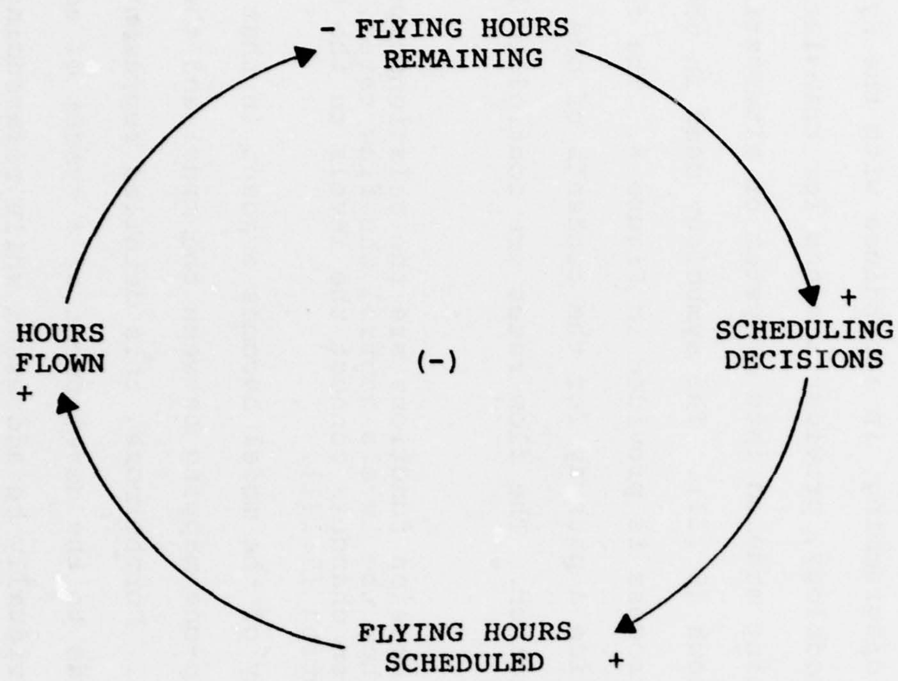

Fig. 7. Causal Loop Diagram of the Flying Hour Sector

Having developed the system model in causal-loop notation, the researchers were then ready to begin the process of preparing the hypothesized model for computerization. A first step in this preparation process was to construct flow diagrams for the model (7:12).

Flow Diagramming

Flow diagramming, in accordance with the System Dynamics methodology, provides a means for translating the system being modeled into a system of alternating levels and flows (5:131). The symbology used in the flow diagramming process is provided in Figure 8. The flow channels provide a pathway for the contents of one level to flow to another. The flow rates are controlled by the levels.

> The decision functions are the relationships that describe how the levels control the flow rates. Information channels connect the levels to the decision function [5:131].

The simplicity of the model becomes evident in that it permits one-to-one mapping between the model and the system being modeled. Furthermore, this detailed representation logically leads to the development of a system of equations that can individually be addressed while referencing the model (5:13). Hence, flow diagramming completes a necessary step toward computerization of the system being modeled.

The actual accomplishment of flow diagramming can best be illustrated by example. Symbology used in this example will, again, be taken from Figure 8. As was indicated in Figure 6, the amount of flying hours usually flown was a variable of interest when investigating the wing level scheduling process. In accordance with System Dynamics methodology, the accumulation of flying hours actually flown could be represented as the accumulation of a quantity in a reservoir (5:76). Hence, when constructing a diagram to represent the flow of flying hours through the system, flying hours flown were represented as a level. The representation of flying hours flown is provided in Figure 9. This level is represented as a quantity which flows in from a source. The rate at which these hours accumulate was hypothesized to be a function of flying hours scheduled, hours scheduled not accomplished, and overflys approved. It can also be noted that the accumulation of flying hours flown provided information to control the level of flying hours remaining. Hence, a flow diagram representing flying hours flown provided an exact representation of the hypothesized relationship of this variable with the rest of the model. The diagram presented in Figure 9 also provided a foundation upon which the mathematical representation of this flow was developed.

The flow diagramming of the model presented in Figure 6 followed the procedure outlined above for each

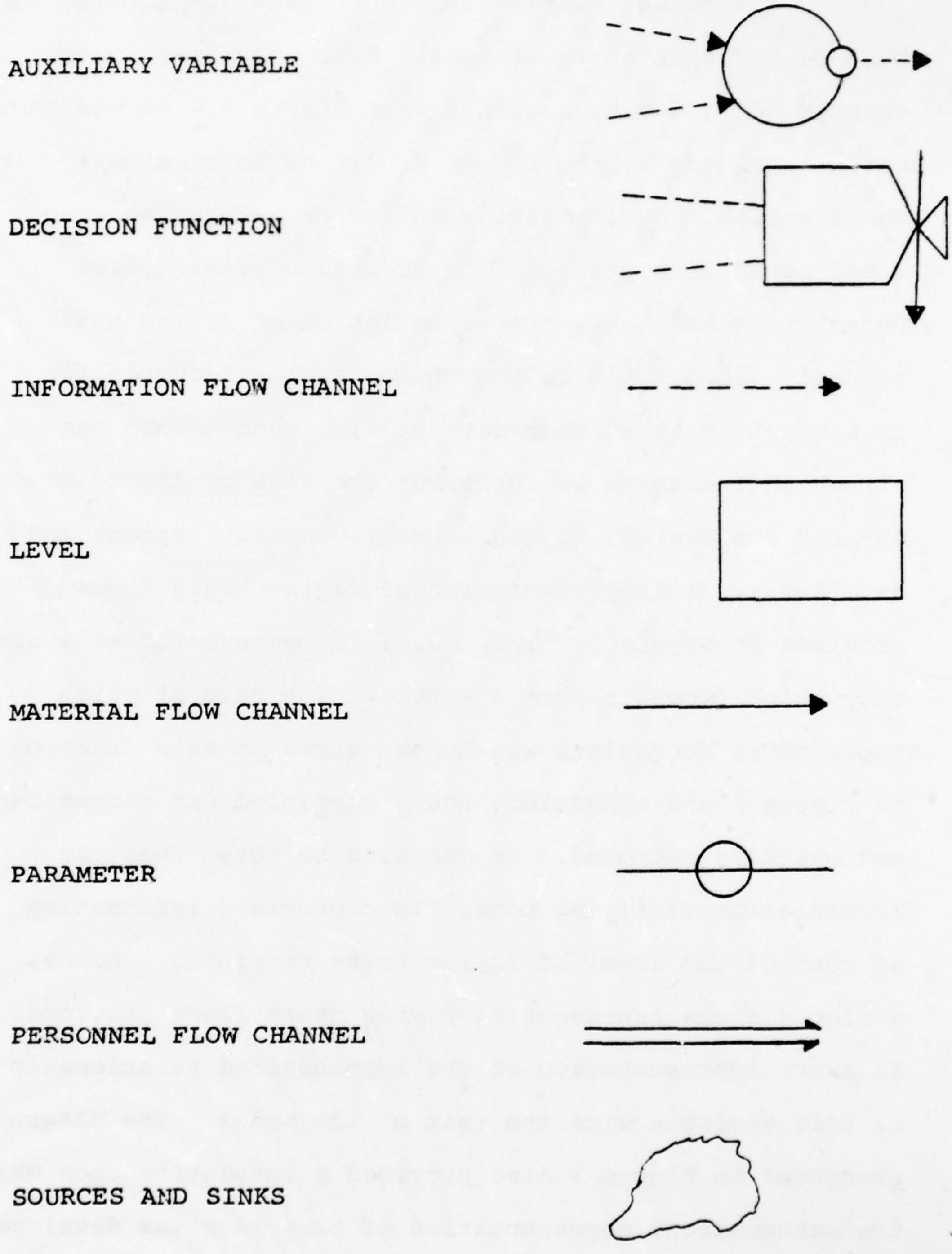

Fig. 8. Symbology (5:82-83)

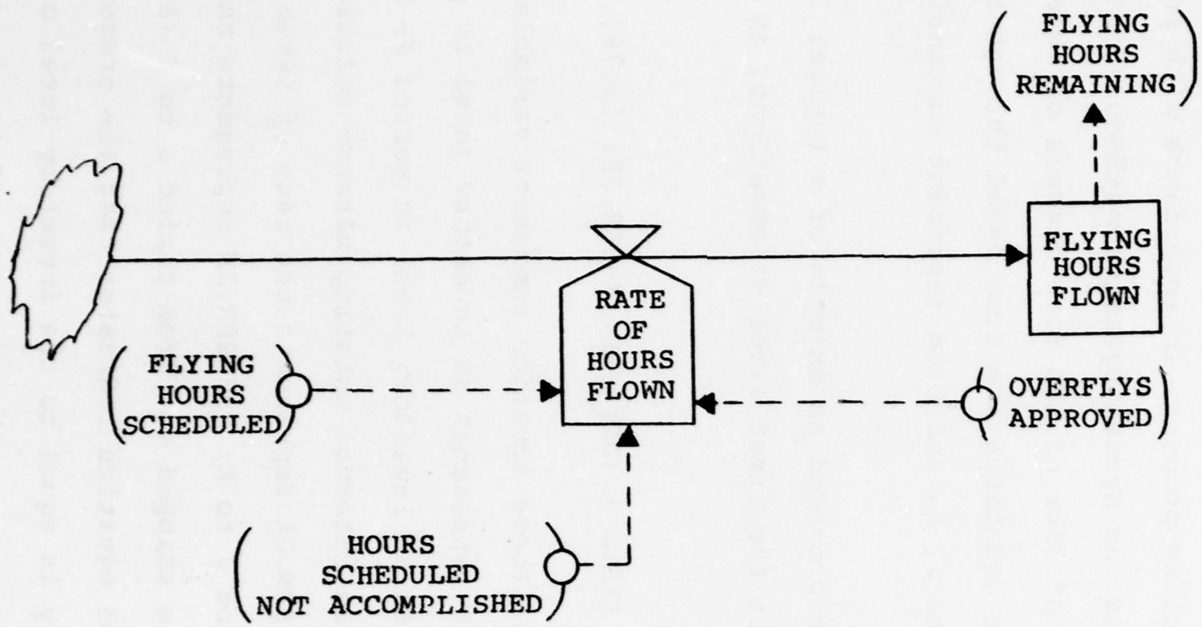

Fig. 9. Flow Diagram of Flying Hours Flown

variable. Once this effort was completed, the model representation was then transformed into a system of equations.

Equations

The construction of a mathematical model of the wing level scheduling process, in accordance with research objective five and the System Dynamics methodology (5:13), required the use of four of the five classes of equations (5:77-79). These equations are time based through the use of the letters J, K, and L to represent successive time periods.

Forrester provided an example of a typical level equation, which is the first class of equations, as follows:

"IAR.K = IAR.J + (DT)(SRR.JK-SSR.JK) [5:76]."

The symbols in the above equation represent variables. For example, IAR.K represents an inventory level in period K; IAR.J represents an inventory level in period J; DT represents the time interval existing between solutions to the equation; SRR.JK represents the rate of inventory receipt from period J to K; and SSR.JK represents the rate which inventory is shipped out from period J to K (5:76). Simply stated, the equation indicates that the present level of inventory is equal to the inventory level of last period plus the inventory that was shipped in since last

period minus the inventory that was shipped out since last period.

A second class of equations used in System Dynamics is the rate equation which is used to represent the decision function (5:77). "The rate equations define the rates of flow between the levels of the system [5:77]." It was noted in the above equation that SRR.JK represented the rate of inventory receipt from period J to K (5:76). It is then evident that if this rate is multiplied by a given length of time, a quantity will be produced which can properly be added to or subtracted from the previous inventory level.

The remaining three classes of equations; i.e., auxiliary, supplementary, and initial-value equations (5:78-79), provide additional tools for completing a mathematical model. Auxiliary equations provide a means of simplifying rate equations. Since a rate of flow may be based on many different constraints, auxiliary equations provide a means of combining these different inputs so as to reduce the complexity of the rate equation itself. Supplementary equations can be used to establish variables which are not inherently part of the model structure (5:74). For example, "We may wish to compile information (like the sum of all inventories in the entire system) that is not used in any of the decision processes of the model [5:79]." Initial-value equations are used to provide

beginning values for all levels and some rates for the computerized model (5:79). These initial value equations are a necessary part of the model computerization effort.

In this study of the wing level scheduling process, appropriate equations, such as those outlined above, were developed so as to mathematically represent the hypothesized model. This mathematical representation provided the framework necessary to enter the model onto the DYNAMO computing system.

Model Behavior

After the appropriate equations had been determined, the model was computerized in order to produce the behavior of the model through time. This crucial step insured that the model correctly encompassed identified factors, relationships, information flows, and decision policies (5:13). For example, it was hypothesized that the level of required maintenance is positively related to the level of required maintenance accomplished. If the model had not reacted in the expected manner, the researchers would have had to take corrective action.

Appropriate corrective action may have included any of a number of alternatives. It would seem most appropriate to check the accuracy of the equations first. If the equations are accurate, the researcher should check the flow diagram to insure that this diagram encompasses

all of the relationships identified in the causal-loop diagram. The last step would be changes to the causal-loop diagram.

While representative samples of model behavior can ensure that the model correctly represents the system as viewed by the researcher, this same sample behavior does not, however, ensure that the model was a valid depiction of the actual system.

Model Testing

In assessing the validity of the model, Forrester's thoughts again came to mind.

> The validity (or significance) of a model should be judged by its suitability for a particular purpose. A model is sound and defendable if it accomplishes what is expected of it. This means that validity, as an abstract concept divorced from purpose has no useful meaning [5:115].

As noted by Forrester, the purpose of the model is a crucial factor that must be considered when one attempts to assess the model's validity. Thus, the evaluator is drawn back to the ideas of Chapter I. As stated in the Research Question, the purpose of these efforts was to determine if the structure of the scheduling process could be incorporated into a dynamic model. Hence, a determination of model validity necessarily required a comparison of model-generated behavior with actual wing behavior.

In order to generate model behavior for evaluative purposes, several basic data elements had to be

obtained from the comparator wing and input into the model. These test data included:

1. The average number of flying hours allocated.

2. The average number of aircraft assigned.

3. The average number of maintenance personnel assigned by specialty.

4. The average number of operations personnel assigned by speciality.

5. The average total number of training items required by speciality.

6. Examples of typical Operations and Maintenance schedules.

7. Results of the above Operations and Maintenance schedules.

This data listing provided all inputs needed to begin the validation process.

These wing data were used to provide the major initial inputs to the model. The model was then executed over various time periods. The results obtained from the model were compared with actual results. The model was "judged on the basis of system behavior--stability, periods of fluctuations, timing relationships between variables, and amplitudes of system fluctuation [5:133]." These variables describe the general character of the system (5:133). If the model had not described the general

character of the system, appropriate corrective action would have been taken.

Corrective action can take the form of rechecking input accuracy or completely redesigning the model. The researcher should first check the accuracy of information, equations, and the flow diagram. If these inputs are found to be accurate, then major changes to the causal-loop diagrams, and hence, the model, may be required. While describing the general character of the system is an important criteria test, there is one additional requirement for a successful System Dynamics model (5:133).

Forrester (5:133) indicated that the final determinant of the success of a System Dynamics model is its ability to help managers design better systems. It is to this end that the final two objectives were devoted. Studying the effect of change on system behavior was a prerequisite to understanding the requirements necessary for efficient scheduling. Changes were made to various policies in the model. The results of these changes led to an identification of several variables which were sensitive to change. The identification of these sensitive variables aided significantly in understanding the requirements for efficient scheduling, the concluding objective of this research effort.

Having reviewed the systems methodology that was used in this study, it is now appropriate to begin a more detailed review of the actual application techniques.

CHAPTER III

CAUSAL-LOOP DIAGRAMS

Introduction

Chapters I and II provided initial insight into both the research task at hand and the foundation on which this study was based. It is now possible, therefore, to begin a detailed presentation of the actual activities which occurred. A logical starting point is to present a discussion of the rationale which was used to develop the causal-loop diagram of the wing level schedule process as shown in Figure 6, page 33.

As presented in Figure 6, the wing level scheduling process was conceptualized as eight interacting sectors. These sectors included: the Flying Hour Remaining Sector, the Crews Available for Ground Training Sector, the Crews Available for Flying Training Sector, the Maintenance Personnel Available for Training Sector, the Aircraft Availability Sector, the Maintenance Training Requirements Sector, the Flying Training Requirements Sector, and the Ground Training Requirements Sector. This figure further indicated that scheduling decisions lie at the heart of this hypothesized process. It seems appropriate, therefore, to begin the following discussion with the focal point of the entire scheduling process--*scheduling decisions*.

Scheduling Decisions

While scheduling decisions are being presented first in the chronology of this discussion, it must be acknowledged that *scheduling decisions* were not defined as a separate entity in the course of the actual research until all of the hypothesized sectors had been identified and constructed. A few words of explanation should provide insight as to why *scheduling decisions* were identified last in research and yet are presented first in this discussion.

It was quite easy to develop many of the individualized sectors that are combined into Figure 6. As the research continued, however, it became increasingly apparent that what was being identified was, indeed, individualized sectors. These sectors, as initially conceived, had no common point. A reexamination of the identified sectors, however, led to a realization that the motivating force that generates all activity within each sector was missing. As was noted by Forrester,

> . . . a "policy" is a rule that states how the day-by-day operating decisions are made. "Decisions" are the actions taken at any particular time and are a result of applying the policy rules to the particular conditions that prevail at the moment [5:93]

Forrester's comments emphasized that guiding policy prescribes how an organization is to operate. Operating decisions, on the other hand, actually spur organizational activity.

When considering the wing level hierarchial structure in terms of executive-level policy makers and operational decision makers, it is hypothesized that the executive wing staff--the Wing Commander, the Vice Commander, the Deputy Commander for Operations, the Deputy Commander for Maintenance, and the Deputy Commander for Resources--are the policy makers for the individual wing. It is further suggested that these executive-level policy makers base their policy decisions not only on the definitive requirements levied by Higher Headquarters (HHQ) and their collective perceptions of HHQ policy, but also on their individualized perceptions of the processes involved in a wing operation.

The operating level, on the other hand, is hypothesized to be at the squadron commander/staff level. Staff functions include, as would be expected, operations and maintenance scheduling activities (11; 14). As suggested by Forrester, these staff-level personnel provide the day-to-day decisions necessary for a wing's operation. A realization of the types of resources controlled by these scheduling functions--personnel, material, and aircraft--made the relationship of the scheduling organization to the identified sectors intuitive. Hence, the motivating factor which also serves as a common link between all identified sectors was hypothesized to be the decisions of the scheduling organization; i.e., *scheduling decisions*.

With the identification of the heart of the wing-level scheduling process complete, it is now permissible to begin a discussion of the individualized sectors and the rationale on which they were based. The discussion will begin with the Flying Hour Remaining Sector.

Flying Hour Remaining Sector

The Flying Hour Remaining Sector, when isolated from the total process depicted in Figure 6, appears as shown in Figure 10. Recalling the discussion on causal-loop diagramming from Chapter II, the forces included in this sector are apparent. Figure 10 shows that the current level of flying hours remaining, as derived from the wing's quarterly allocation, tends to influence the amount of hours that are scheduled to be flown during the upcoming scheduling period. This quantity of hours scheduled, in turn, influences the amount of hours that will be flown. Finally, the amount of hours flown during the upcoming period will influence the amount of flying hours remaining for the following period. Thus, the loop is complete. The nature of these influencing factors, however, remains to be discussed.

Figure 10 indicates that flying hours remaining are positively related to flying hours scheduled. This relationship becomes apparent when one remembers that a primary task of the operations scheduler is to, as

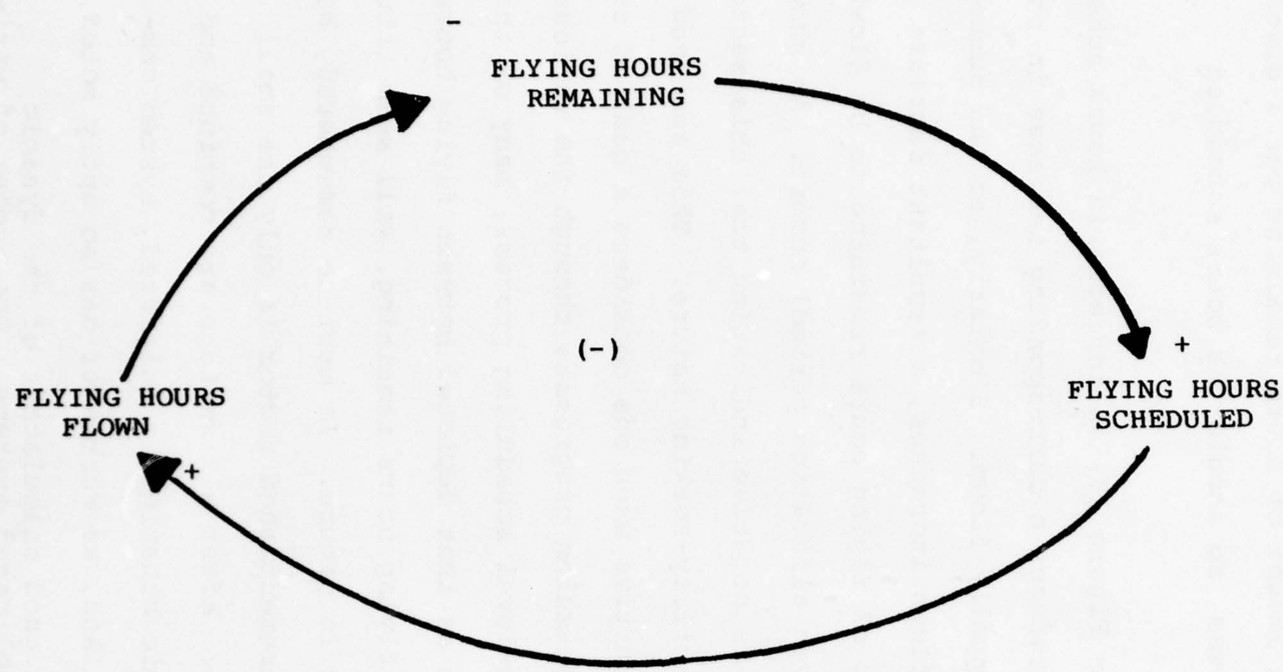

Fig. 10. Flying Hour Remaining Sector--Causal Loop

evenly as possible, schedule all of the allocated flying hours to facilitate crew flying requirement accomplishment (1). Thus, as the amount of hours remaining for a given time period increases, so should the hours scheduled to be flown.

As shown in Figure 10, an increase in hours scheduled to be flown produces a corresponding increase in the number of hours actually flown. Similarly, as the number of hours actually flown increases, a resultant decrease in the total number of flying hours remaining to be flown (again within a given allocation period) occurs. As shown, total loop valence is negative indicating that this sector is of a goal- or stability-seeking nature. This assigned valence becomes intuitive when one considers a goal of zero.

As this discussion progresses through the various sectors of the wing-level scheduling process, many of the relationships, such as that depicted between flying hours actually flown and flying hours remaining, will seem intuitive and simplistic in nature. It must be remembered, however, that this aforementioned sector is only one small part of the process. After all sectors are combined and the resulting dynamic behavior is initiated, system complexity increases. And, as Forrester has so aptly noted,

> Men are not good calculators of the dynamic behavior of complicated systems. The number of variables that they can in fact properly relate to one another is very limited [5:99].

When a systemic process such as that presented in Figure 6 is considered, one can certainly appreciate the wisdom reflected in Forrester's comments. Hence, the methodical process of conceptualizing a system first in terms of sectors, then as variables within the sectors, and finally as the relationships between the variables, is surely a logical approach.

One final point is to be noted prior to leaving the Flying Hour Remaining Sector. As can be observed, nowhere in Figure 10 are Scheduling Decisions explicitly identified. And yet, several times throughout the discussion of this sector, scheduling considerations were acknowledged. The amount of flying hours remaining is an important consideration of the operations scheduler; the number of hours actually scheduled is a result of the decision-making process, and the number of hours flown is directly influenced by the decision-making results. Thus, scheduling decisions will be implicit in all identified relationships although these same decisions will never be explicitly identified. It is now possible to address the (operations) Crews Available for Ground Training Sector.

Crews Available for Ground Training Sector

When isolated from the total process depicted in Figure 6, the Crews Available for Ground Training Sector

can be represented as shown in Figure 11. Figure 11 shows that, utilizing the same logic as presented in Chapter II and the Flying Hour Remaining Sector, the number of operations crews available for ground training positively influences the number of crews scheduled for ground training and, consequently, the number of crews who have accomplished ground training. These completed crews will, in turn, reduce the number of crews available for ground training inasmuch as upon ground training completion, a crewmember will usually be considered for flying training activity first and then, if no flying training is assigned, will be considered for further ground training (1).

This ordering of requirements highlights the first inclusion, thus far, of an executive-level policy in the model. As was indicated by Loring AFB scheduling officers (1), it is more difficult to complete a crewmember's assigned flying requirements than it is for assigned ground training requirements. The rationale behind this assertion can be appreciated when one considers the many factors which can cause the cancellation of assigned flying activity as opposed to the few ways in which assigned ground training remains unaccomplished. Thus, the Crews Available for Ground Training Sector must necessarily include a negative (or inverse) relationship between crews scheduled for flying training and crews available for ground training.

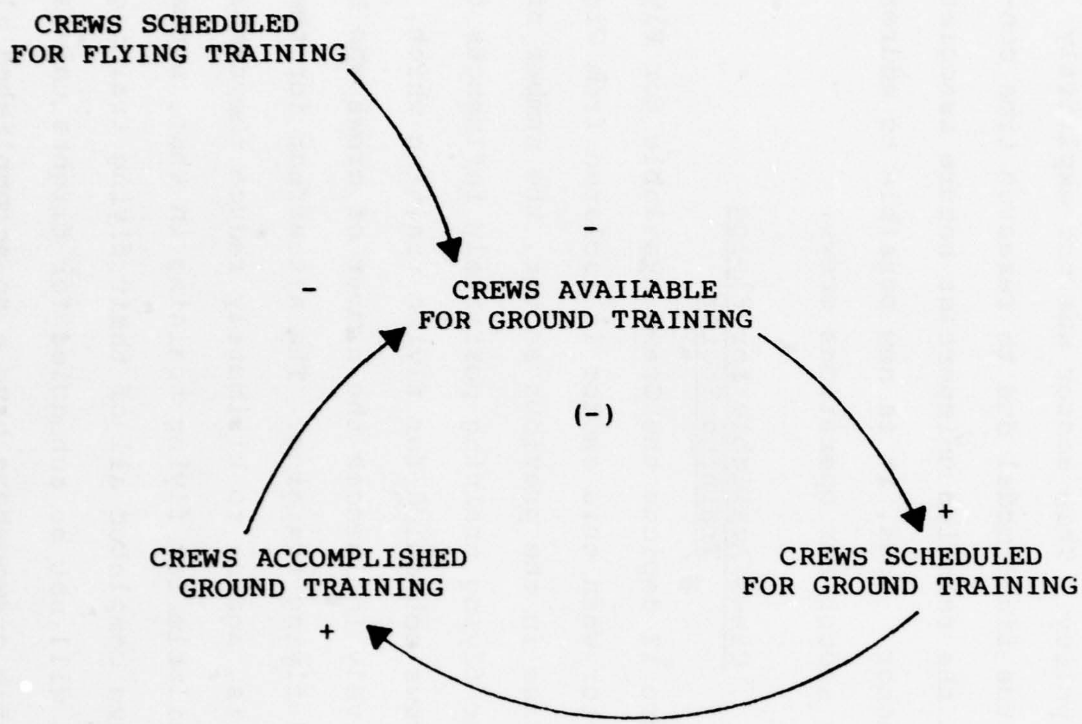

Fig. 11. Crews Available for Ground Training--Causal Loop

The crews available for ground training loop is assigned an overall negative valence, thus indicating a stability-seeking nature. As can be seen in Figure 6, however, this entire loop is strictly a subset of the Crews Available for Flying Training Sector, as is suggested by actual wing policy. This sector was not explicitly detailed in the final model due to research time constraints and the relative unimportant nature associated with this sector. Thus, it is now possible to address the priority sector for operations crews.

Crews Available for Flying Training Sector

Figure 12 depicts the Crews Available for Flying Training Sector when this sector is isolated from Figure 6. As was the case in the previous sector, the number of crews available for flying training positively influences the number of crews scheduled for flying training which, in turn, positively influences the number of crews who have accomplished flying training. The net effect for the entire loop is, again, to ultimately reduce the number of crews available for flying training in that, normally, crews who have completed all of their flying training requirements will not be scheduled for flights unless all other available crewmembers have also accomplished all of their flying training requirements. A complete

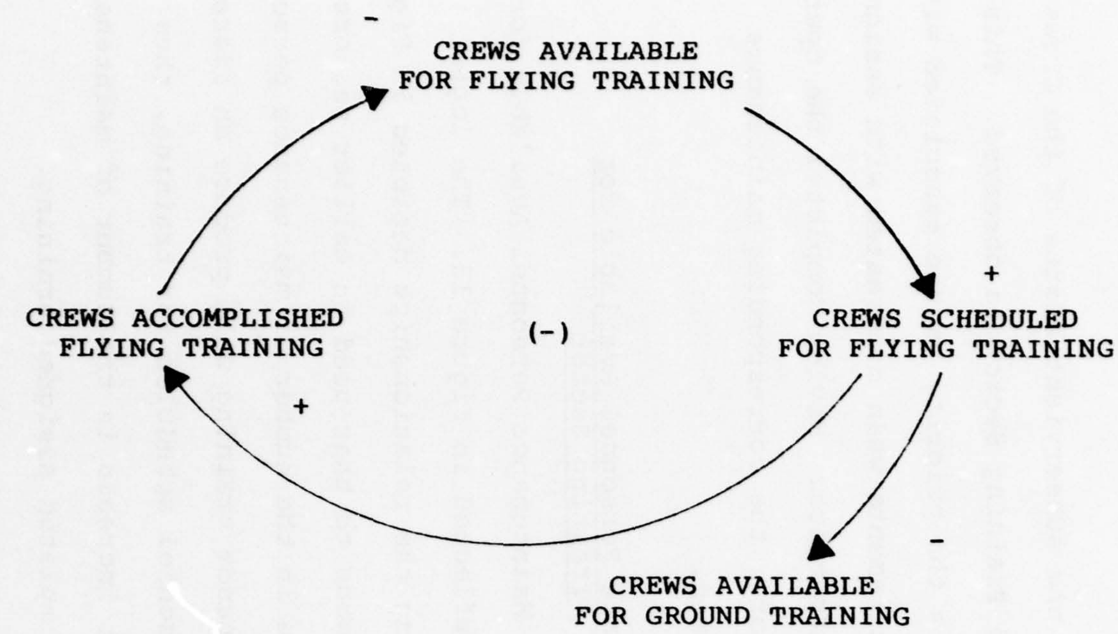

Fig. 12. Crews Available for Flying Training--Causal Loop

non-availability of crewmembers who have not completed all of their assigned flying training requirements is normally the exception rather than the rule (1). Once again, overall loop valence is negative, thus indicating a stability-seeking loop.

Once again, the subservient status of the Crews Available for Ground Training Sector is observed. This status again reflects the priority nature associated with flying training requirements when contrasted with assigned ground training requirements. Having completed the operations personnel sectors, the corresponding maintenance sector can be addressed.

Maintenance Personnel Available for Training Sector

The isolated Maintenance Personnel Available for Training Sector is reflected in Figure 13. The logic utilized in developing the relationships depicted in Figure 13 is directly analogous to that used in earlier sectors. As shown, an increase in the number of maintenance personnel available for maintenance training will produce an increase in the number of personnel scheduled for training, thus producing a resultant increase in the number of maintenance personnel who have completed assigned training.

During the conceptualization of this sector, it was decided to include required aircraft maintenance within

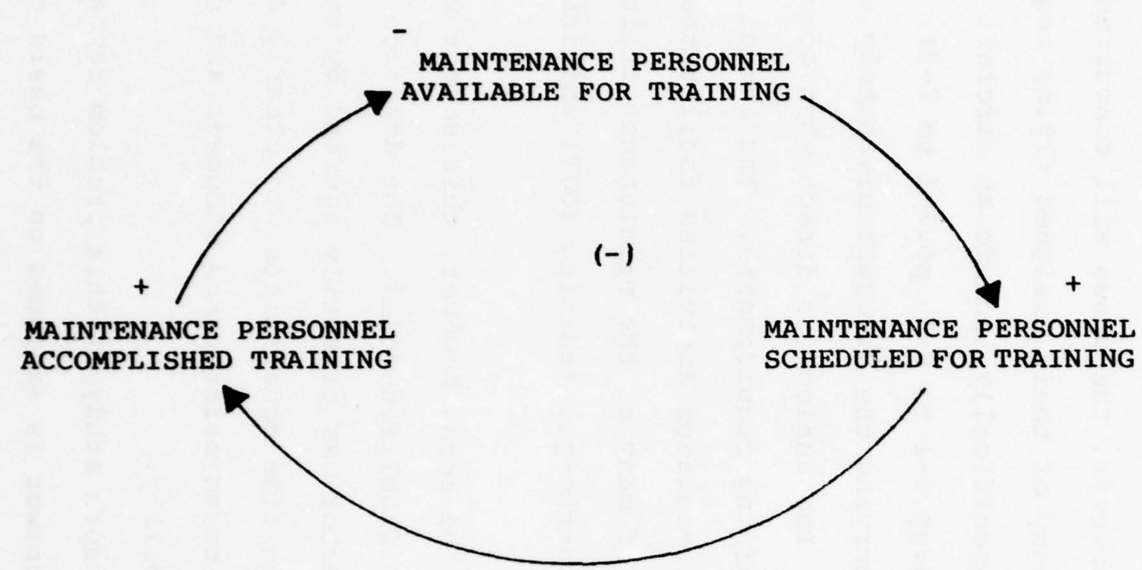

Fig. 13. Maintenance Personnel Available for Training Sector--Causal Loop

the maintenance training requirements. The rationale used to support this hypothesis is similar to that used in crew training requirements. For example, operations crews may be tasked to ferry an aircraft to another base to permit depot-level maintenance on the aircraft. During the flight to the depot, however, the crews will concurrently be accomplishing many of their assigned flying requirements, none of which specifically include an aircraft ferrying requirement (15:pp.6-1 to 6-5, pp.7-1 to 7-3). Thus, the sheer act of ferrying the aircraft ulitmately accomplishes two functions. The analogy is direct when considering maintenance training requirements. The actual accomplishment of aircraft-related activities facilitates the accomplishment of many of the maintenance training requirements such as on-the-job training (OJT) and initial qualifications (11).

As will be seen, however, this sector was not included in the finalized model. The decision to not include this sector was primarily spurred by an inability, within the given time constraints, to clearly define the relationship between maintenance manpower and sortie-producing capability.

An in-depth study of this problem revealed that maintenance manpower is assigned on the basis of the fiscally-approved flying hour allocation (4:2-3). It is then presupposed, based on a standard sortie length, that

a given level of maintenance manpower can produce a given sortie capability. This sortie capability is then associated with the wing and its assigned personnel.

Telephone conversations with Loring AFB maintenance personnel (11), however, revealed that the wing had the ability to far exceed its associated weekly sortie capability when confronted with surge conditions. While this ability bespeaks highly of both the spirit and leadership contained at Loring AFB, it provides little insight into the true nature of sortie production. Time-between-takeoffs seemed to be one of the primary factors associated with sortie production. As revealed by the Loring AFB personnel, a reduction in the time-between-takeoffs produces a corresponding decrease in sortie-producing ability. Thus, a positive relationship is implied between these two variables. Also, assigned manpower seems to be positively related to sortie production. However, other limiting factors must exist. It was the inability of the researchers to explicitly define (as opposed to quantify) these other factors, within the allotted time constraints, that ultimately led to the decision to not include this sector in the finalized model. The determination of these other factors and their associated relationships with sortie production capability is highly recommended for future research efforts. It is now appropriate to address perhaps the most important sector in this model.

Aircraft Availability Sector

The Aircraft Availability Sector, when isolated from the total process shown in Figure 6, can be represented as shown in Figure 14. This sector reveals the complex nature of aircraft flows within a wing. Many resultant wing activities, represented as subloops within the structure, are inherently generated by forces represented in the outer, aircraft available for flight, loop. A further breakout of the subprocesses represented in Figure 14 will lead to greater understanding of the total process encompassed in this sector. For example, the outer loop of Figure 14 represents one of the subprocesses involved in this sector and is shown in Figure 15.

This outer loop represents a familiar flow of influence similar to that seen in earlier sectors. As shown, the number of aircraft available for flight is positively related to the number of aircraft scheduled for flight and, consequently, to the number of aircraft flown. The net effect, in turn, is to reduce the number of aircraft available for flight. Also, as shown, the overall valence for the loop is negative implying a stability-seeking condition. Similarly, the innermost loop of Figure 14 is also of a stability-seeking nature and is shown in Figure 16. As shown, an increase in the amount of required maintenance will tend to increase the amount of required maintenance accomplished, thus resulting

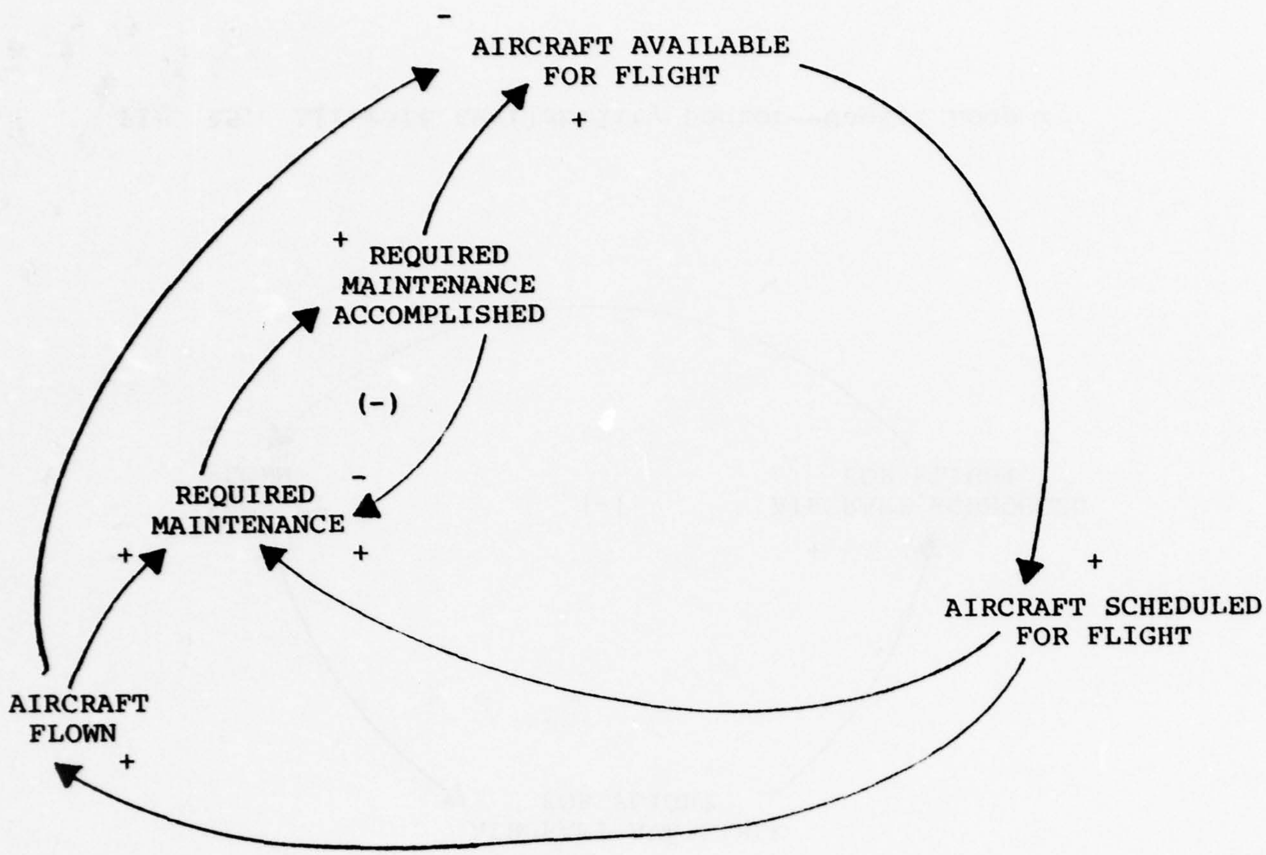

Fig. 14. Aircraft Availability Sector--Causal Loop 1

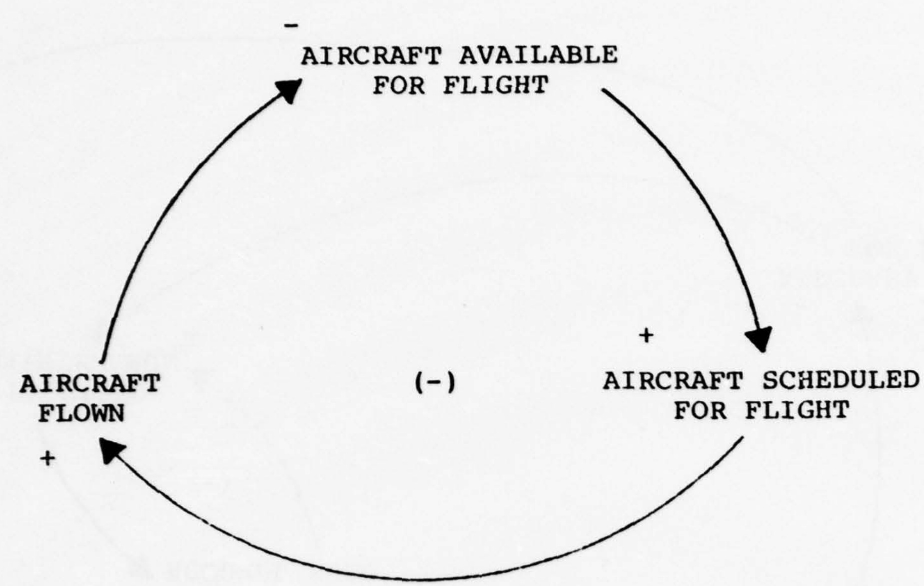

Fig. 15. Aircraft Availability Sector--Causal Loop 2

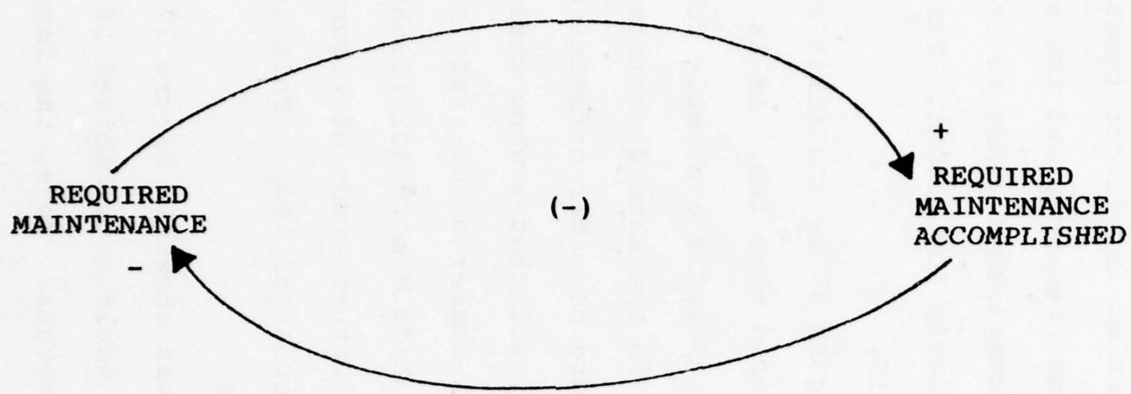

Fig. 16. Aircraft Availability Sector--Causal Loop 3

in a net decrease in the amount of required maintenance--hence, the stability-seeking nature.

Figure 14 further reveals, however, that the number of aircraft scheduled for flight tends to influence the amount of required maintenance, and the amount of required maintenance accomplished tends to influence the number of aircraft available for flight. This structure is presented in Figure 17.

Presented in Figure 17 is the first growth/decay-oriented sector encountered thus far. As is shown, any change in the number of aircraft available for flight will tend to be perpetuated (in the same direction) around the loop. Thus, if there were no other offsetting factors included in this sector, all that a wing would have to do to increase its total number of aircraft available for flight is, simply, to schedule more for flight. Obviously, such is not the case. Further study of Figure 14 reveals one other growth/decay-oriented loop. This loop is represented in Figure 18.

Once again, as was shown in Figure 17, a growth/decay-oriented behavior would be exhibited if it were not for other intervening factors. Thus, the important question becomes--"What prevents these processes exhibited in Figures 17 and 18 from ultimately going out of control?" The answer lies in the two negative relationships presented in Figure 14. An increase in the number of aircraft flown

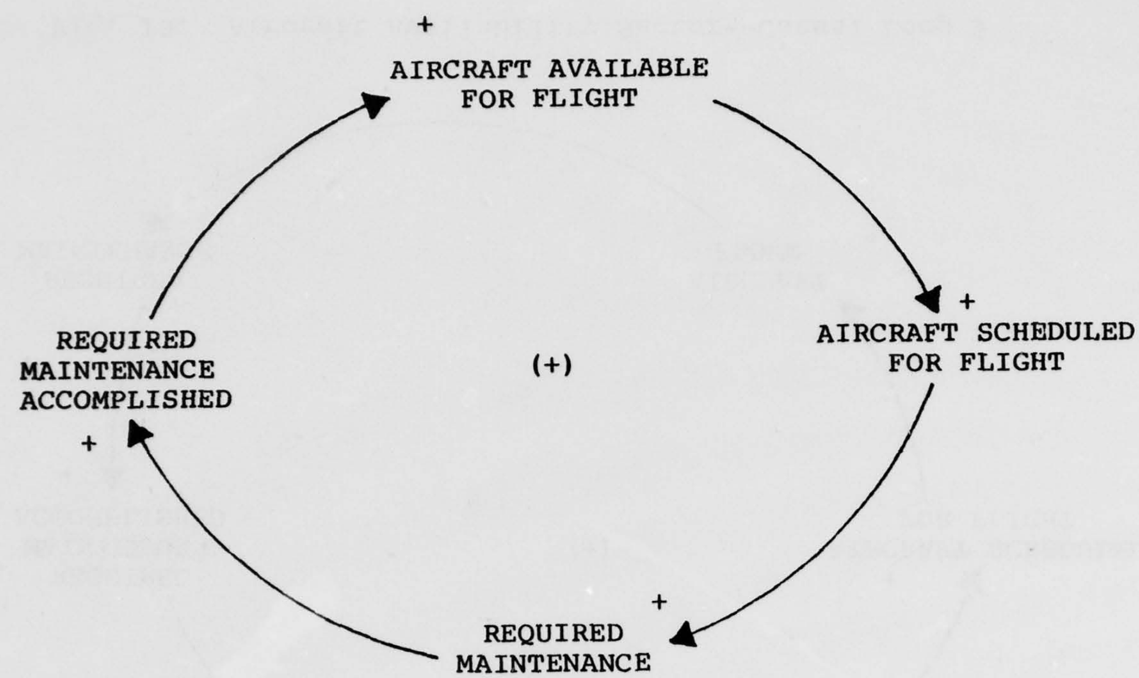

Fig. 17. Aircraft Availability Sector--Causal Loop 4

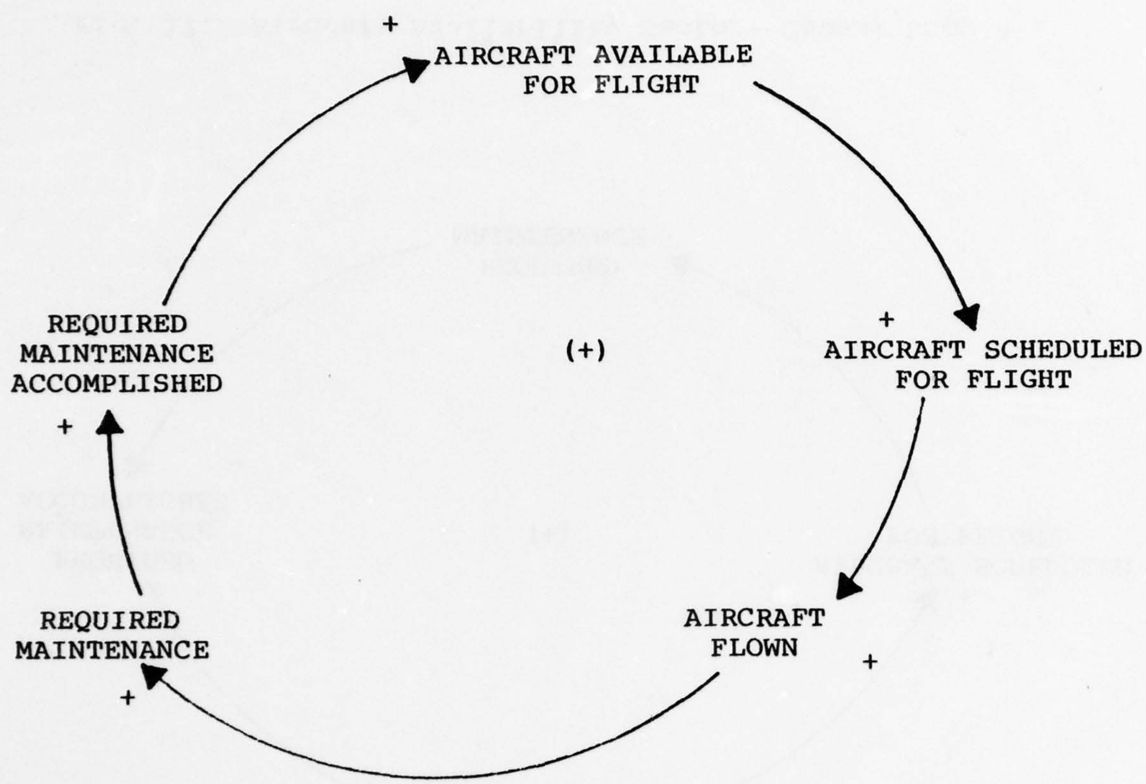

Fig. 18. Aircraft Availability Sector--Causal Loop 5

will tend to decrease the number of aircraft available for flight, thus acting as a moderator to prevent the uncontrolled growth that was possible in both Figures 17 and 18. Similarly, Figure 14 shows that the variable required maintenance is controlled through its interaction with required maintenance accomplished. Hence, the seemingly explosive nature of the process represented in Figure 14 is controlled through two key relationships. Controls such as these must exist if the process is to continue through time. The next sector to be considered will be the Maintenance Training Requirements Sector.

Maintenance Training Requirements Sector

The Maintenance Training Requirements Sector is shown in Figure 19. The process represented by this structure is not unlike those presented earlier. As shown, the number of maintenance training requirements remaining is positively related to the number of requirements scheduled and, therefore, to the number of requirements accomplished. The net result is to reduce the number of requirements remaining thus yielding a negative, or stability-seeking, loop.

This sector, however, could not be included in the finalized model due to the inability, as previously discussed, to include the maintenance personnel sector.

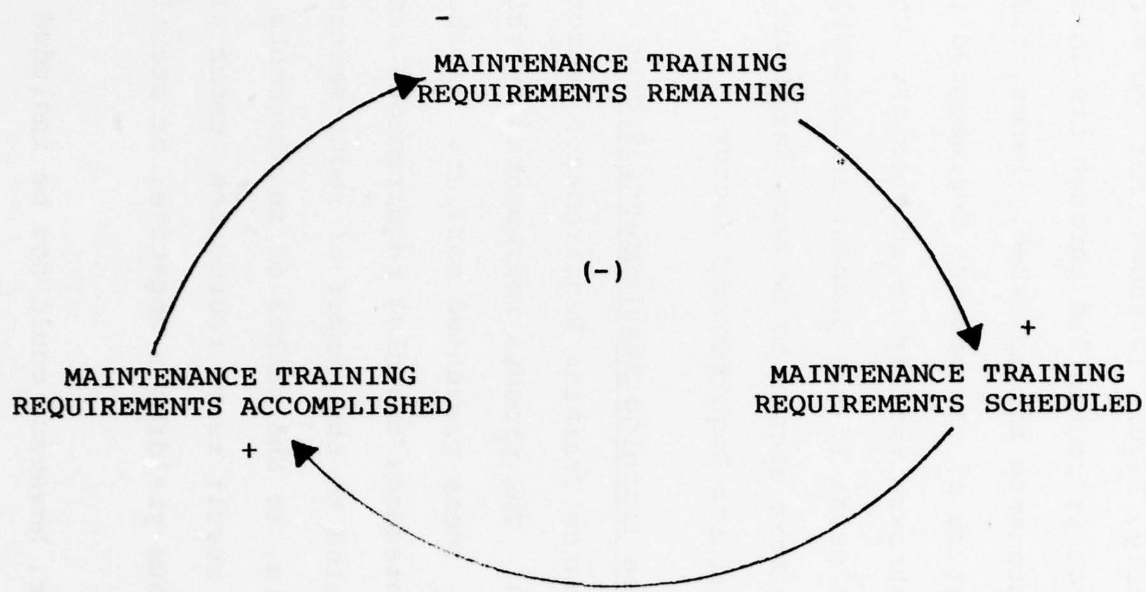

Fig. 19. Maintenance Training Requirements Sector--Causal Loop

Once the personnel sector problems are revolved, inclusion of this sector will be relatively simple.

Flying training requirements are one of the underlying drivers of the total process presented in Figure 6. Hence, a discussion of this sector is important.

Flying Training Requirements Sector

The accomplishment of requirements is one of the primary motivators of a wing's activities. This sector is presented in Figure 20. The nature of this sector is similar to that presented in earlier discussions. As shown, an increase in the total number of flying training requirements remaining will tend to increase the number of requirements scheduled and, consequently, the number of requirements ultimately accomplished. Thus, an initial increase in requirements remaining eventually results in a decrease in this same variable.

When considering the importance associated with this sector, several points should be emphasized. A primary purpose of an operational wing is to maintain some perceived level of ability to wage war. In order to maintain this level of ability, the command structure will levy a given quantity of training requirements that must be accomplished. Coincident with the requirements assignment, a wing is also provided the resources (for example, crews, aircraft, flying hours, and maintenance) to facilitate the accomplishment of these assigned tasks. Thus,

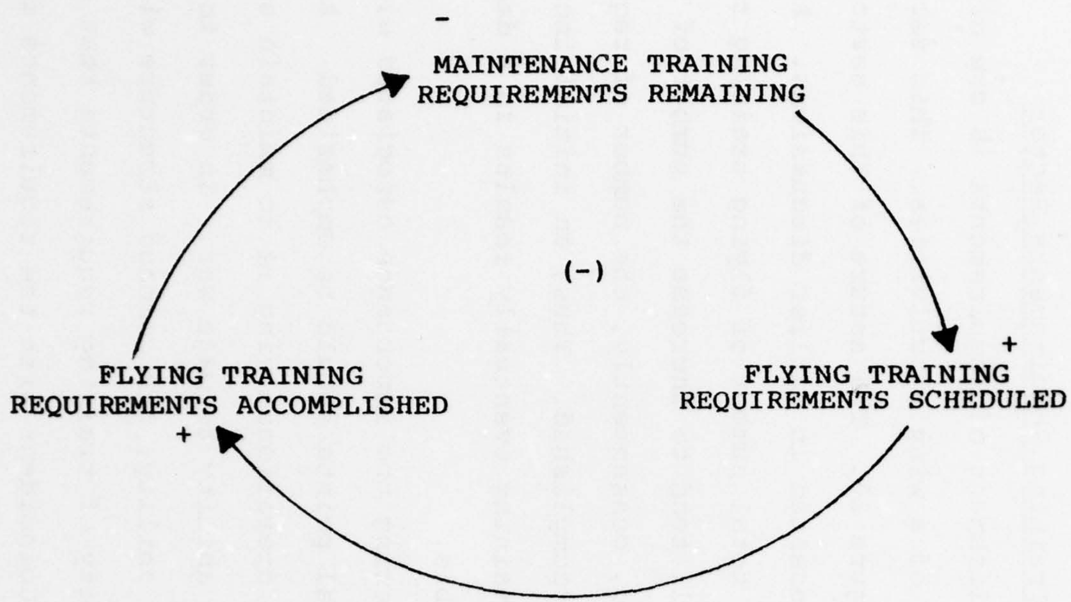

Fig. 20. Flying Training Requirements Sector--Causal Loop

the potential for goal accomplishment exists. In order to provide a measure of incentive for requirements accomplishment, SAC wings are required to report to HHQ both the numbers of requirements accomplished and not accomplished (14). Hence, the number of remaining requirements receives considerable attention by the wing staff. The remaining sector of the process presented in Figure 6 will now be discussed.

Ground Training Requirements Sector

The isolated (from Figure 6) Ground Training Requirements Sector is presented in Figure 21. The Ground Training Requirements Sector is similar in nature to earlier sectors. The number of ground training requirements remaining tends to positively influence the number of requirements scheduled and, in turn, the number of requirements accomplished. The ultimate result is to decrease the number of remaining requirements. Once again, it is possible to observe the stability-seeking nature of the loop.

This sector, as was the case with the Maintenance Training Requirements Sector, was not included in the finalized model due to the noninclusion of the Crews Available for Ground Training Sector. Due to the priorities associated with flying requirements versus ground training

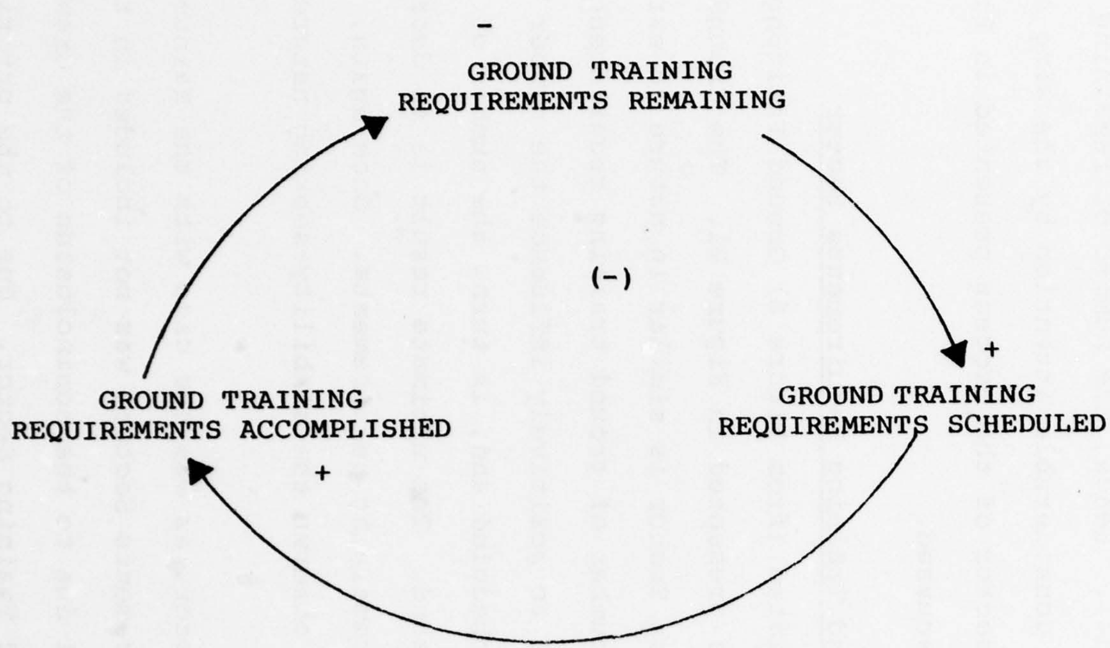

Fig. 21. Ground Training Requirements Sector--Causal Loop

requirements, no major influences are omitted from the overall process by not including this sector.

Thus, the detailed presentation of the process is complete. Once again it must be emphasized that while these aforementioned sectors were presented in an individualized format, the overall process must be considered as a whole. Each part, whether it be a sector or single variable, does produce some measure of influence which must ultimately affect the system's behavior. Hence, all parts ultimately influence all other parts. Only through this systemic approach can the actual process involved be represented. In accordance with the System Dynamics methodology and the research objectives outlined in Chapter I, the next topic of discussion will concern the conversion of the process shown in Figure 6 into flow diagrams and a set of mathematical equations.

CHAPTER IV

FLOW DIAGRAMS

Introduction

As is suggested by the System Dynamics methodology, and the research objectives outlined in Chapter I, the system modeler first conceptualizes the system to be modeled, next develops causal relationships, and then develops the expanded system structure from which mathematical equations are to be developed. The purpose of this chapter, therefore, is to present a detailed discussion of the activities which led to the development of system flow diagrams and DYNAMO equations for the wing-level scheduling process. It should be remembered that while the finalized flow diagrams are significantly more detailed than the structure presented in Figure 6, the decision structure represented in Figure 6 remained unchanged.

The following presentation will begin with a detailed development of the sector flow diagrams. Each development will contain an associated graphical representation of that portion of the sector being discussed. Beneath each variable name used in the diagrams, the line number of the associated DYNAMO equation will be indicated.

A complete listing of all variable names used in this model, with associated definitions, is presented in Appendix A. Appendix B contains a finalized listing, with line numbers, of the DYNAMO model. Thus, when encountering a new variable name, the reader can turn to Appendix A for a formalized definition of the variable or to Appendix B to see the associated DYNAMO equation. This mode of presentation will permit greater clarity and understanding. The discussion, therefore, can now continue with the presentation of the Flying Hour Remaining Sector.

Flying Hour Remaining Sector

The system dynamics flow diagram for the Flying Hour Remaining Sector will, due to page size limitations, be presented in subpart fashion. While this method of presentation is somewhat incremental, greater clarity is achieved. For example, Figure 22 presents the level of flying hours remaining and the factors which control flows into and out of this level.

As is shown in Figure 22, the level of flying hours remaining (FHRRMN) at a particular time depends on both the hours assigned (HRSASG) up to that time and the hours used (HRUSRT) up to that time. The ease with which a system dynamics flow diagram is mapped onto the actual system is indicated by HRSASG. As is the case with the operational

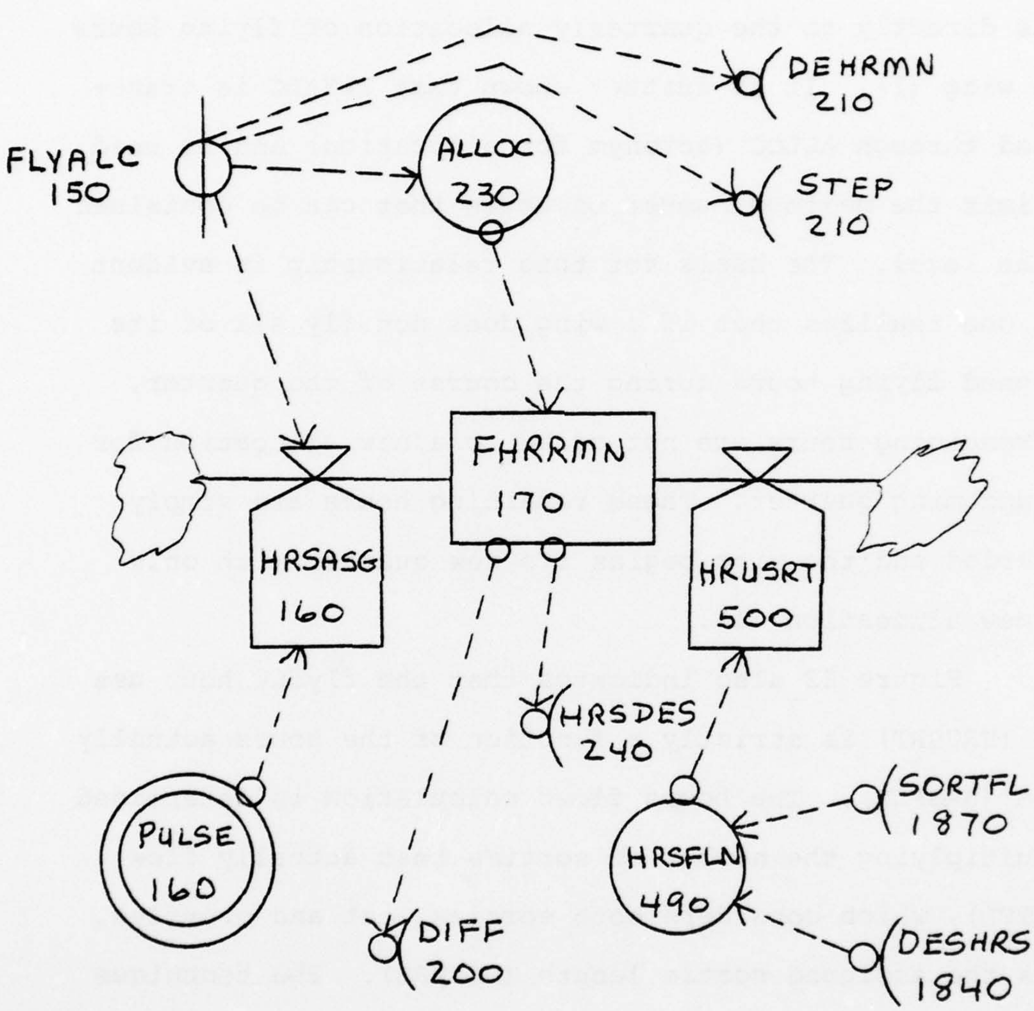

Fig. 22. Flying Hours Remaining Sector--
Flow Diagram 1

wings, Figure 22 indicates that a given quantity of flying hours, the flying hour allocation (FLYALC), will be pulsed into the level intermittently. This relationship corresponds directly to the quarterly allocation of flying hours to a wing (1). It is further shown that FLYALC is transmitted through ALLOC (acronym for allocation) and is used to limit the maximum number of hours that can be contained in the level. The basis for this relationship is evident when one realizes that if a wing does not fly all of its assigned flying hours during the course of the quarter, the remaining hours are not added to a new allocation for the upcoming quarter. These remaining hours are simply discarded and the wing begins its new quarter with only its new allocation (1).

Figure 22 also indicates that the flying hour use rate (HRUSRT) is strictly a function of the hours actually flown (HRSFLN). The hours flown calculation is determined by multiplying the number of sorties that actually flew (SORTFL), which considers both sorties lost and overflys, times the assigned sortie length (DESHRS). The technique of holding sortie length constant at the amount scheduled and varying SORTFL to account for overflys as well as losses may seem confusing at first. As will be seen, however, the number of hours actually flown will again be calculated in another part of this sector. Furthermore, this second calculation of hours flown will be based on

information obtained from a different part of the system. Hence, the ability to compare these two values of hours flown will allow an observer to ensure that informaton contained in different parts of the system is compatible. A replication of this technique is within the ability of the operating manager. The next subsector to be identified is used to determine the number of flying hours that the scheduler would like to allocate to the upcoming scheduling period, generally one week in most wings (1). The decision structure used to represent the scheduling of flying hours for an upcoming period is presented in Figure 23.

The decision structure presented in Figure 23 reflects the policy guidance a scheduler uses when calculating the number of hours to be flown in the upcoming period. The executive-level policy being represented states that a scheduler, to the maximum extent possible, should evenly spread the wing's quarterly flying hour allocation over all of the weeks within the quarter. This even spreading of hours is suggested for two reasons (1). First, if all of the allocated flying hours were flown in the first half of the quarter, for example, crew proficiency during the last half would begin to deteriorate. Hence, a constant, smooth flow of training provided to the aircrews seems desirable. Second, requesting that maintenance provide all of the allocated flying hours in one

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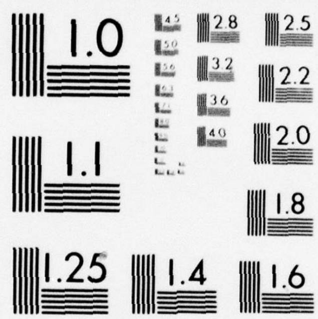

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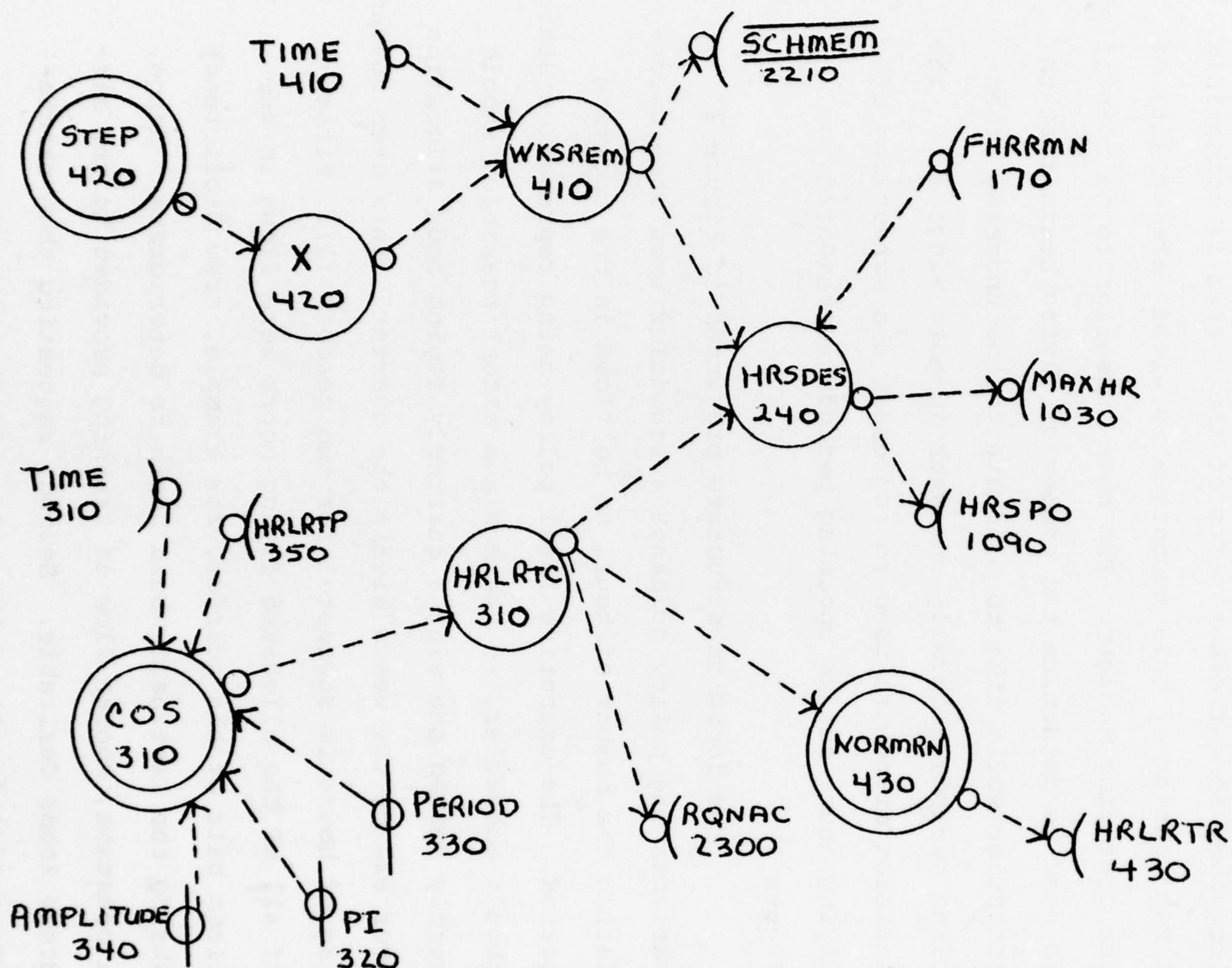

Fig. 23. Flying Hours Remaining Sector--Flow Diagram 2

half of the intended time may be beyond maintenance's capability. Similarly, maintenance would be operating in a no-load condition during the second half of the quarter. This surge condition is contrary to current maintenance objectives (11) and, thus, will be addressed in future discussions.

While reflecting on the implications of the aforementioned scheduling policy, the following question arose. "What does the scheduler do when, for example, 100 hours were scheduled to be flown, but only 50 hours were actually flown?" Are the unaccomplished hours to be scheduled over and above the normal amount for the upcoming period? As revealed by Loring AFB personnel (1), the implied scheduling rule should be followed whether hours remain unaccomplished from the last period or not. This rule states that a scheduler should divide the number of flying hours remaining in the quarter by the number of weeks remaining in the quarter and divide the resulting quotient by one minus the perceived loss rate for the upcoming period. When considering the implications of this rule, it is possible to see that all losses (such as the previously mentioned 50 hours) will be rescheduled in an even fashion over the remaining weeks of the quarter. The net effect of this decision rule is to smooth all flying hour requests presented to the maintenance organization thus precluding, to the maximum extent possible, rapid

variations in demand. A smoothed flow of demands is highly desirable according to maintenance personnel (1). The final division indicated in the scheduling rule is to divide the number of hours to be scheduled for the upcoming week by one minus the perceived loss rate. This calculation produces an effect of overscheduling so as to compensate for some, if not all, of the hours which might be lost. Having thus presented a discussion of the policy and associated decision rule used in the calculation of the desired number of hours to be flown in the upcoming scheduling period, it is now possible to specifically address the structure presented in Figure 23.

A study of Figure 23 and the referenced DYNAMO equations reveals the methods used to generate each variable. As is indicated, X represents the quarterly adjusted total of weeks contained in the present quarter and all past quarters. TIME is internally generated within the DYNAMO model and is a cumulative total of all time up to the present. Thus, the number of weeks remaining in the current quarter (WKSREM) is calculated by subtracting TIME from X. WKSREM, as shown, is used both as an input to the scheduler's memory (SCHMEM) and to the calculation of the number of flying hours to be scheduled for the upcoming scheduling period (HRSDES).

Figure 23 shows that three inputs are required to calculate HRSDES: the number of flying hours remaining

in the current quarter (FHRRMN), the number of weeks remaining in the current quarter (WKSREM), and a perceived loss rate for the upcoming scheduling period (HRLRTC). The methods used to calculate FHRRMN and WKSREM have previously been addressed. Thus, a discussion of HRLRTC remains to be presented.

The scheduler's perception of the flying hour loss rate for the upcoming scheduling period is determined by providing a seasonal adjustment to the average yearly flying hour loss rate which operational wings have experienced. For example, Loring personnel (1) felt that 19 percent reasonably approximates their wintertime loss rate while 5 percent is representative of the summertime rate. These figures produce a yearly average of 12 percent. This yearly average is indicated in Figure 23 as HRLRTP. To provide for a seasonal adjustment of the yearly loss rate, a cosine function is used. This computerized function provides a cosinusoidal wave with an amplitute of seven one-hundredths and a period of fifty-two weeks. An algebraic combination of the average yearly loss rate and the seasonal adjustment factor produces an expected wintertime loss rate of 19 percent with a summertime rate of only 5 percent. Thus the scheduler's perception of the flying hour loss rate for the upcoming period is continuously updated.

The hours desired (by the operations scheduler) for the upcoming period is shown as an input to the calculations of MAXHR, the maximum number of flying hours per aircraft that maintenance is willing to provide for the upcoming period, and to HRSPO, the maximum number of flying hours that are to be scheduled based on operations and maintenance desires. While the discussion of HRSPO is to be presented next, the explanation of MAXHR will be deferred until the Aircraft Availability Sector is presented. Figure 23 further indicates that HRLRTC is an input to both the simulated flying hour loss rate that a wing could actually experience (HRLRTR) and to RQNAC. RQNAC is the number of flying training requirements which were scheduled but not accomplished. The detailed discussion of RQNAC will also be deferred until the presentation of the Flying Training Requirements Sector. It is now possible, however, to detail the development of HRLRTR, HRSPO, and other associated variables.

Another subpart of the Flying Hour Remaining Sector is presented in Figure 24. As shown, the expected flying hour loss rate (HRLRTC), is randomized in a normal distribution to simulate the actual loss rate (HRLRTR) experienced by the wing. In addition to being further utilized within this sector, HRLRTR is also used as an input factor for the calculations of: the number of scheduled aircraft which did not fly (ACSNAF), the number of scheduled

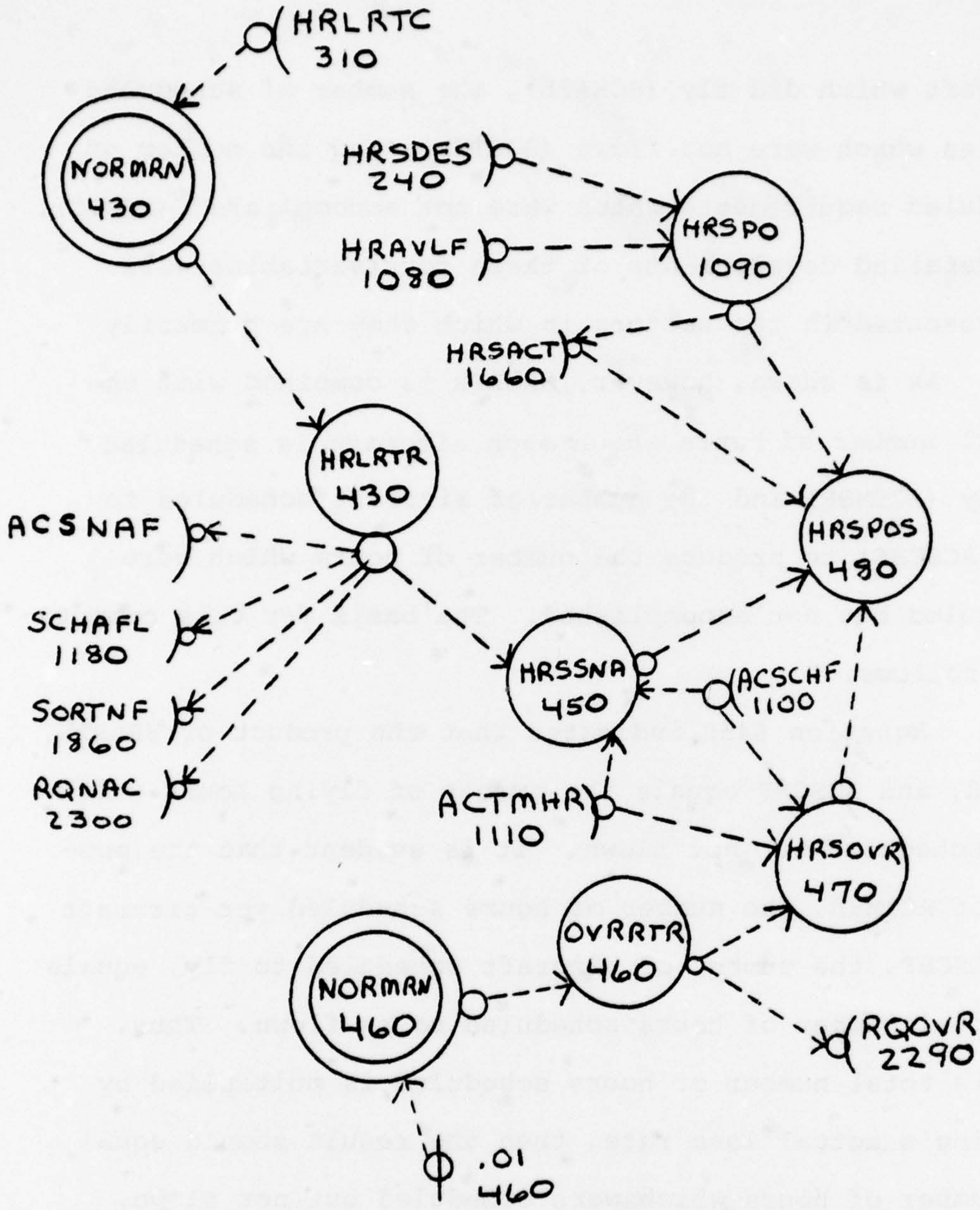

Fig. 24. Flying Hours Remaining Sector--
Flow Diagram 3

aircraft which did fly (SCHAFL), the number of scheduled sorties which were not flown (SORTNF), and the number of scheduled requirements which were not accomplished (RQNAC). The detailed developments of these four variables will be presented in the sectors in which they are primarily used. As is shown, however, HRLRTR is combined with the actual number of hours which each aircraft is scheduled to fly (ACTMHR) and the number of aircraft scheduled to fly (ACSCHF) to produce the number of hours which were scheduled but not accomplished. The basis for this computation follows.

Equation #450 indicates that the product of HRLRTR, ACTMHR, and ACSCHF equals the number of flying hours which were scheduled but not flown. It is evident that the product of ACTMHR, the number of hours scheduled per aircraft and ACSCHF, the number of aircraft scheduled to fly, equals the total number of hours scheduled to be flown. Thus, if this total number of hours scheduled is multiplied by the wing's actual loss rate, then the result should equal the number of hours which were scheduled but not flown. The number of hours overflown (HRSOVR) is similarly produced.

Equation #470 indicates that the number of hours flown in excess of the number scheduled is equal to the product of ACTMHR, ACSCHF, and OVRRTR, the overfly rate. OVRRTR is simulated by randomizing, in a normal distribution, an average overfly rate that a wing might experience.

Loring schedulers indicated that it is not uncommon to experience a 1 percent increase in average sortie length for those sorties that do overfly. Hence, it is possible to simulate the number of hours that would be overflown.

As was previously discussed, HRSPO is the maximum number of flying hours that are to be scheduled based on operations and maintenance desires. The decision rule captured in the HRSPO relationship (Equation #1090) is that no more hours will be scheduled than that number which was desired by operations but constrained by maintenance. Loring personnel confirmed this relationship (1). There is, however, one other limiting factor in the determination of the number of hours that are actually scheduled (HRSACT), this being the restrictions imposed by operations crew availability. While the detailed development of HRSACT is deferred to the Crews Available for Flying Training Sector, the use of HRSACT in determining the number of hours actually flown (HRSPOS) can be shown.

As Equation #480 indicates, HRSPOS equals the number of hours scheduled (HRSACT) plus the hours overflown (HRSOVR) minus the hours which were scheduled but not accomplished (HRSSNA). In a previous discussion, however, the number of hours actually flown (HRSFLN) was shown to be the total number of sorties that flew (SORTFL) multiplied by the scheduled sortie length (DESHRS). This

apparent inconsistency in logic is resolved when two observations are made. First, the number of sorties that flew (Equation #1870) is equal to the number of sorties that were scheduled to be flown (SORTIE--Equation #1850) minus the number of sorties that did not fly (SORTNF--Equation #1860). Second, SORTNF is based on HRLRTR, the actual loss rate, but is also adjusted for overflys, based on OVRRTR. Hence, SORTFL is adjusted for both sorties lost and sorties overflown. Thus, HRSFLN, as defined by Equation #490 should always equal HRSPOS. The equality of these varibles ensures that multiple areas of the system are compatible. It is now possible to address the final portion of the Flying Hour Remaining Sector.

Presented in Figure 25 is the final portion of the Flying Hour Remaining Sector. This diagram presents the calculation of the difference between the actual number of flying hours remaining (FHRRMN) and the desired number of flying hours remaining (DEHRMN).

In earlier discussions, the executive-level policy which prescribes how the allocated flying hours are to be distributed over the quarter was presented. This policy indicated that the assigned flying hours are to be distributed as evenly as possible over the quarter. A resultant scheduling rule was also presented. The rule stated that the maximum number of hours to be scheduled for the next period is to be no more than the number

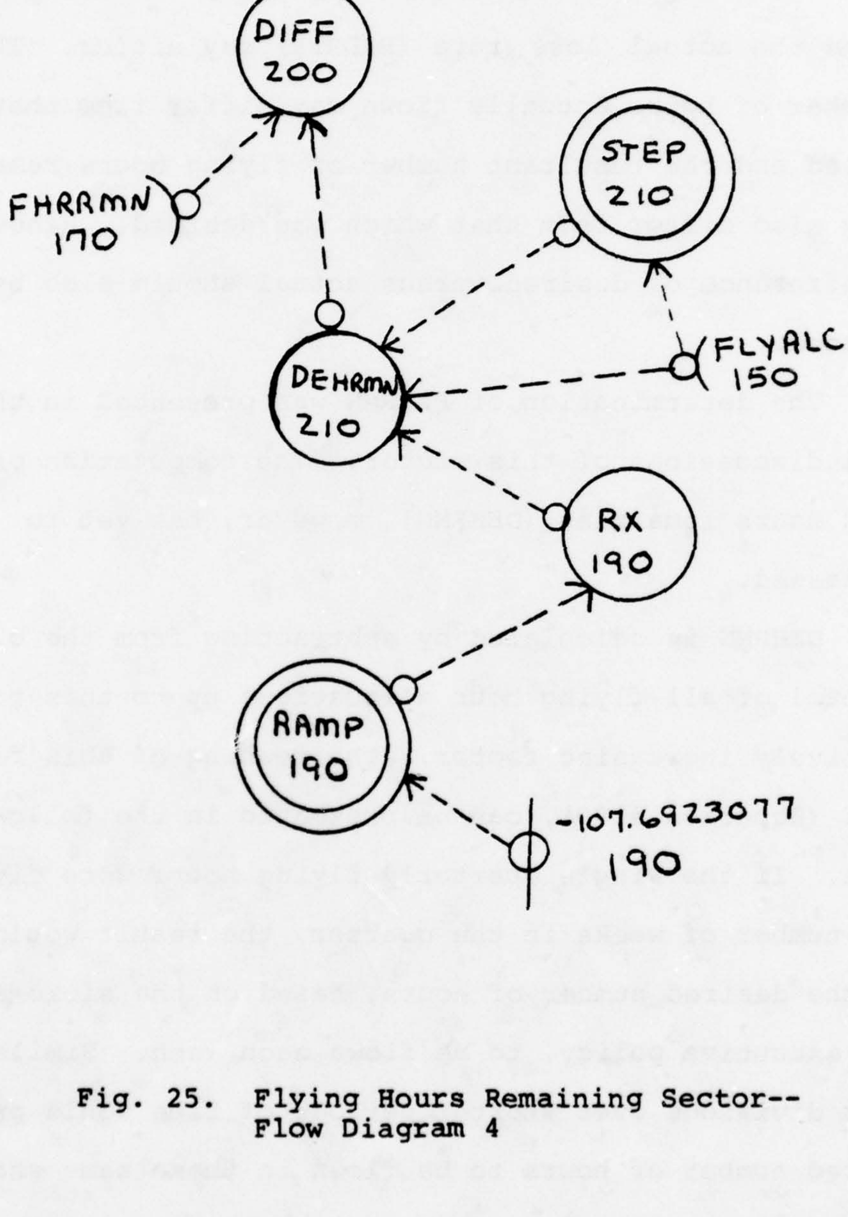

Fig. 25. Flying Hours Remaining Sector--
Flow Diagram 4

of hours remaining (FHRRMN) divided by the number of weeks remaining in the quarter (WKSREM) and further divided by one minus a perceived loss rate (HRLRTC) for the upcoming period. As was pointed out, however, the perceived loss rate and the actual loss rate (HRLRTR) may differ. Thus, the number of hours actually flown may differ from that scheduled and the resultant number of flying hours remaining may also differ from that which was desired. Hence, this difference of desired versus actual should also be calculated.

The determination of FHRRMN was presented in the initial discussions of this sector. The computation of desired hours remaining (DEHRMN), however, has yet to be addressed.

DEHRMN is calculated by subtracting from the cumulative total of all flying hour allocations up to this point a negatively increasing factor. The meaning of this factor, RX (Equation #190), can be presented in the following fashion. If the wing's quarterly flying hours were divided by the number of weeks in the quarter, the result would equal the desired number of hours, based on the aforementioned executive policy, to be flown each week. Similarly, further divisions over shorter periods of time would produce a desired number of hours to be flown in these same shorter periods. In the limiting sense, a desired number of hours could be calculated for one instant of time. If a

cumulative total, which begins at zero and continues through time, of these instantaneous amounts of desired hours was plotted on a set of horizontal/vertical axes, the plot should appear as a line sloping upward to the right. Likewise, the plot could be made negative and, hence, would be downward sloping to the right. This downward sloping plot represents a plot of the variable RX. With a time of zero superimposed at the origin of the axes, and with time increasing to the right, the value of RX will decrease (increase in a negative direction) as one moves through time. Thus, the algebraic addition of RX and the cumulative total of all flying hour allocations up through the current quarter produces the desired number of flying hours remaining in the quarter at the present time. It is, therefore, possible to calculate the difference between FHRRMN and DEHRMN, the result of which is DIFF.

Having thus completed a review of the Flying Hour Remaining Sector, it is now appropriate to address what was termed earlier as the most important sector in this system.

Aircraft Availability Sector

The Aircraft Availability Sector is the most important sector in this system. The reason is intuitive.

Without aircraft, a flying wing cannot accomplish its assigned mission.

Interviews with Loring AFB maintenance personnel (11) revealed that a wing's aircraft may be found in any one of five possible levels. These levels include:

1. An available level. Aircraft which are neither serviced nor equipped for any particular mission, but require no major maintenance prior to being scheduled for an activity.

2. An in-maintenance level. Aircraft which are currently undergoing major maintenance (maintenance which cannot be performed in a fifteen-hour turnaround from the last landing to the next scheduled takeoff).

3. An on-alert level. Aircraft which are currently in an alert status.

4. A no-fly level. Aircraft which are being prepared for or are awaiting a scheduled activity, but ultimately will not participate in the activity. For example, many hours are required to prepare a B-52 for flight. If some malfunction precludes an on-time takeoff, several additional hours may be spent trying to correct the malfunction so that some part of the scheduled mission can be completed. If maintenance personnel cannot repair the malfunction in an appropriate amount of time, the mission will be cancelled. The net result, however, is to have

involved maintenance resources and the aircraft for, perhaps, many hours. Hence the need for a no-fly level.

5. A fly level. Aircraft in this level are those which have been scheduled for a flight and subsequently complete part, if not all, of that flight.

From the descriptions of the aforementioned levels, it is possible to conceptualize the four processes through which aircraft may flow. These processes include a maintenance cycle, an alert cycle, a no-fly cycle, and a fly cycle. The source of all four flows is the available pool.

In addition to the flows of aircraft, there are also flows of information throughout this sector. Therefore, it is possible to visualize this sector as consisting of five subparts, the four flows of aircraft and the informaton network. It is in this same five-part format that the Aircraft Availability Sector will be developed. The first subpart to be discussed is the flow of aircraft through required major maintenance.

The flow of aircraft from the available level, through the maintenance process, and back into the available level is shown in Figure 26.

Initial comments on Figure 26 should include the rationale for taking aircraft out of the available pool (since the available level was defined as aircraft not requiring major maintenance) and placing them in the maintenance process. The reason is one of convenience in that

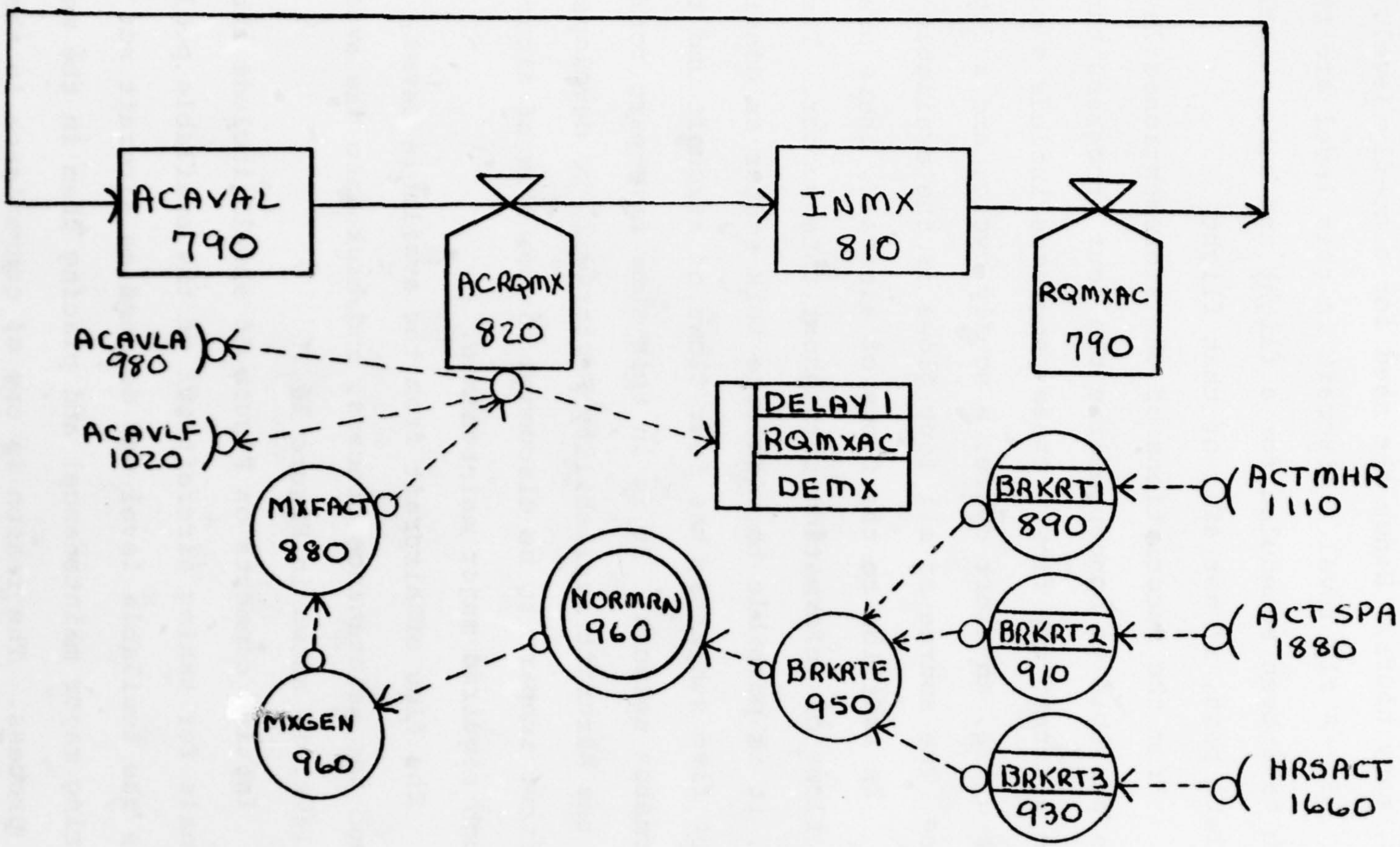

Fig. 26. Aircraft Availability Sector--Flow Diagram 1

system behavior is not altered by this procedure. It is fully acknowledged that an aircraft may land after a flight and flow directly into a major maintenance status. In the DYNAMO model, however, the same effect is produced since nowhere in the system are aircraft identified specifically by tail number. In the overall operation of a wing, the critical nature of major maintenance does not lie in the fact that a specific aircraft is involved. This important nature of major maintenance stems from the large reduction in usable resources that a wing experiences when one or more of its aircraft are involved in major maintenance. Thus, the behavior of this system is not adversely affected by selecting aircraft to enter the maintenance process from the available level. One other initial comment should be made concerning the process indicated in Figure 26.

As stated earlier, aircraft that flow into this process are those which have been designated for major maintenance. Recalling the initial discussion of this sector, major maintenance is classified for purposes of this research as required maintenance which cannot be performed in a fifteen-hour aircraft turnaround from last landing to next scheduled takeoff. Maintenance personnel at Loring AFB (11) indicated that it is almost a necessity to have fifteen hours from the time an aircraft lands until the next time it is scheduled to takeoff. These

fifteen hours allow from four to six hours for normal servicing (such as fuel and oil) in preparation for the next flight and approximately ten hours to make repairs as needed. While these figures may seem rather excessive initially, a moment's reflection on the age and complexity of the B-52 will enhance understanding. It was therefore realized that any interruption of this fifteen-hour landing-to-takeoff flow of scheduled aircraft that is caused by additional required maintenance is sufficient to be classified as major maintenance. Loring personnel (11) indicate that an attempt will be made to switch the malfunctioning aircraft to a later takeoff time. This procedure, however, is very difficult to successfully accomplish with the B-52. The significant amount of time required to prepare for any scheduled flight has already been indicated. Additionally, the B-52 training missions are of a very individualized nature each focusing on a particular set of training objectives (1). Thus, a unique set of preparatory actions may be required in response to a change in the aircraft's originally scheduled mission. It is therefore possible for large amounts of time and resources to be required in the switching of an aircraft to other than its originally intended mission. This additional preparation time combined with the uncertainties as to when the original malfunction will be repaired highlights the difficulties associated with last-minute tail number

changes. As will be seen, however, normal system operation only maintains a minimum number of aircraft in the maintenance process.

Figure 26 indicates that the number of aircraft requiring maintenance (ACRQMX) is a function of the number of aircraft available (ACAVAL) and the variable MXFACT. ACAVAL has already been defined as the number of aircraft available at any given time. Thus, a derivation of MXFACT should be presented.

As shown MXFACT is the result of a process which combines a series of three break or failure rates. These three break rates are developed specifically to address the three factors which can increase the overall aircraft failure rate (failure indicating major maintenance, in the previous context, is required) realized by a wing.

Loring maintenance personnel (11) indicated that three factors can increase the overall aircraft failure rate realized by a wing. The first factor is flying hours. Considering a week as the scheduling period, as the number of hours per aircraft per week (ACTMHR) increases, the probability that it will require major maintenance (as used above) similarly increases. This probability is identified in Figure 27 as BRKRT1. While the relationship is intuitive, quantifying it is quite another matter. It was indicated (11) that data should be available to produce the desired values. It was also noted, however,

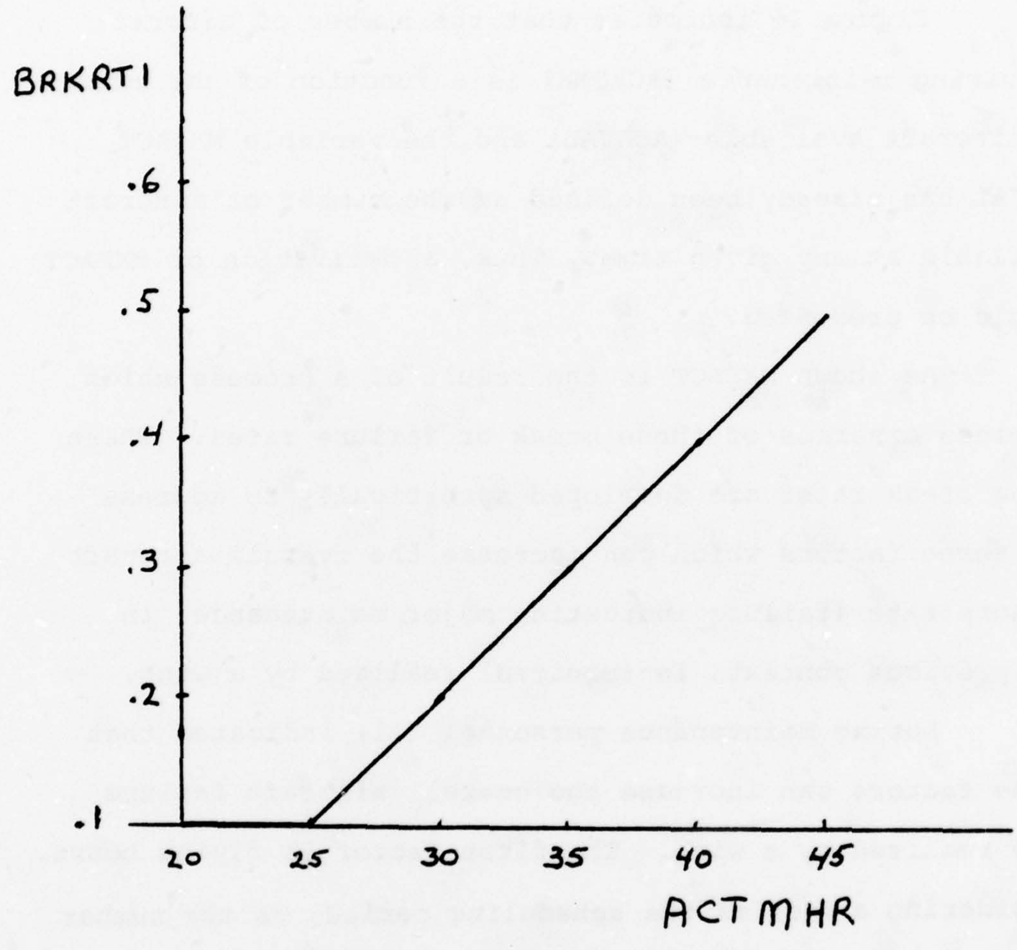

Fig. 27. BRKRT1 Graph

that a considerable amount of time might also be required to gather these data. After an in-depth discussion with Loring personnel (11) concerning the nature of BRKRT1, the relationship presented in Figure 27 was developed. As shown in Figure 27, no increase in failure probability is indicated for twenty-five hours per aircraft per week or less. An increase above twenty-five hours, however, does precipitate an increase in failure probability. The increase in BRKRT1 is considered to be linear up to the forty-five-hour point. As indicated, BRKRT1 peaks at 0.5. Additional comments concerning BRKRT1 will be presented after all three failure factors have been presented.

The second factor which is considered to influence the overall failure rate realized by a wing is the number of sorties that each aircraft is tasked to fly per week (11). The failure probability associated with sortie rates has been identified as BRKRT2 and is shown in Figure 28 as being influenced by the number of sorties flown per aircraft per week (ACTSPA). BRKRT2 has a minimum value of .1 and peaks at 0.6. Further comments, again, will be made after the presentation of the third and final factor which is considered to influence a wing's overall failure rate.

The third factor which is considered to influence the overall aircraft failure rate realized by a wing

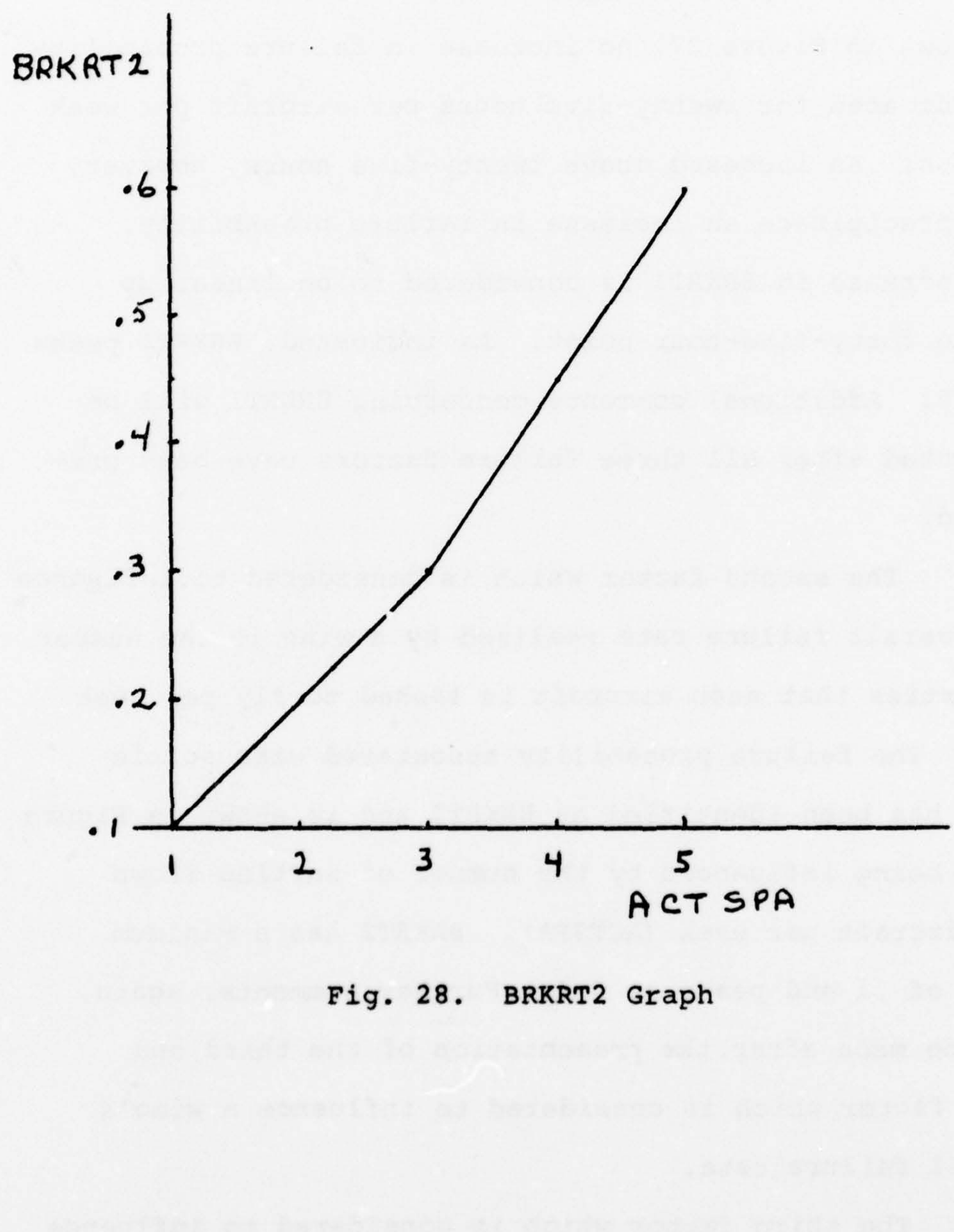

Fig. 28. BRKRT2 Graph

concerns the total level of effort involved (11). BRKRT1 and BRKRT2 specifically addressed the consequences of increasing the utilization of the aircraft, on an individual aircraft basis. An increase in the total level of effort, however, can precipitate an increase in the overall failure rate even though BRKRT1 (based on hours per aircraft per week) and BRKRT2 (based on scheduled sorties per aircraft per week) remain the same. For example, an operational wing usually operates with a relatively fixed number of resources in terms of personnel and aircraft (1; 11). If the wing had been operating with three aircraft available, flying a total of ninety-nine hours per week, and a total of nine sorties, each aircraft presumably would have flown thirty-three hours and three sorties. If this same wing, however, completes maintenance on three additional aircraft and is now operating with six aircraft available, then one may initially feel that twice as many total hours and twice as many total sorties would be possible with no increase in overall failure rate. While it is true that the above scenario would produce no increase in hours per aircraft per week (ACTMHR) or sorties flown per aircraft per week (ACTSPA), it is generally felt (11) that a resultant increase in overall failure rate would occur. Two reasons were mentioned as primarily causing this increase. First, the wing is now operating six aircraft instead of three. This

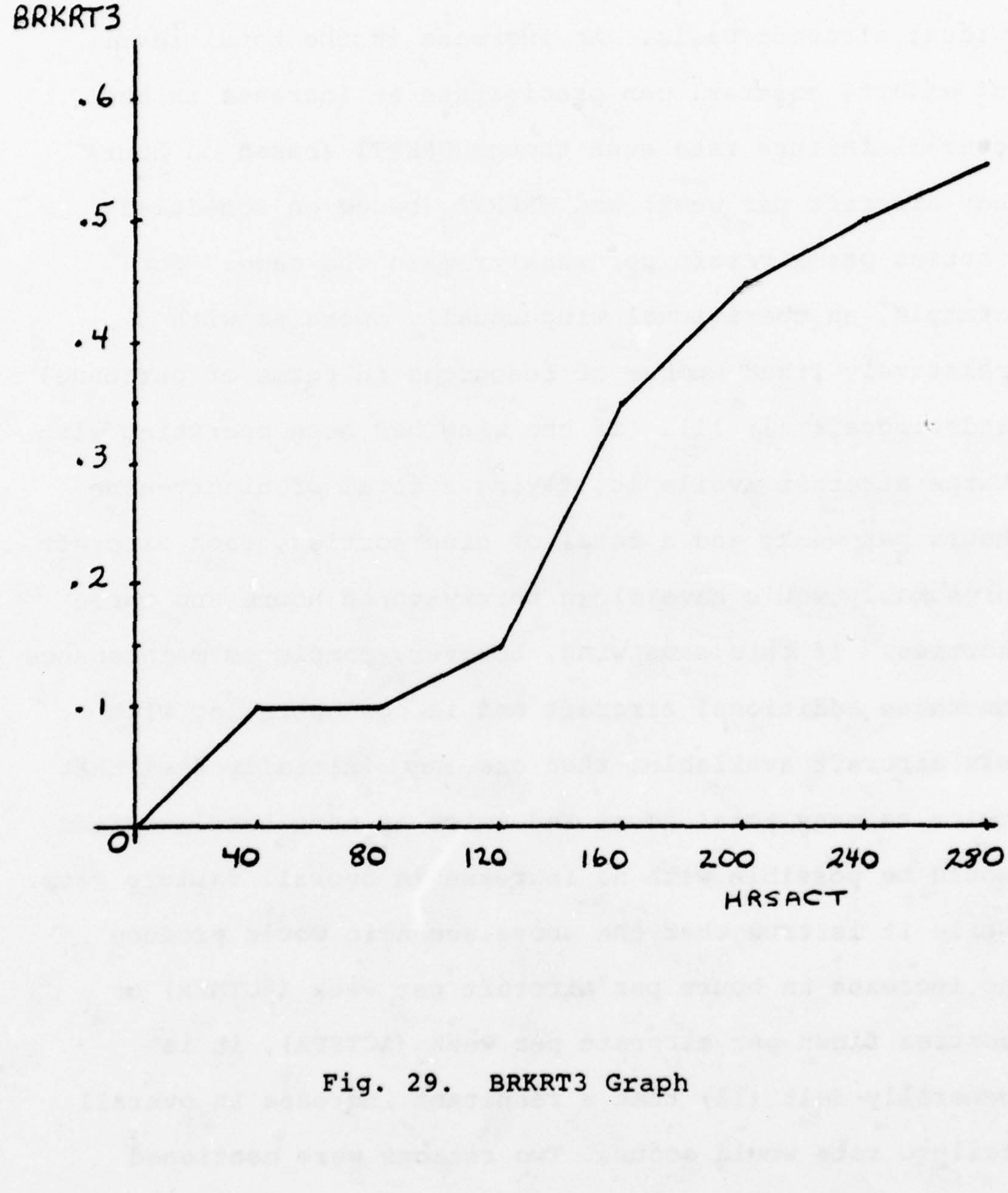

Fig. 29. BRKRT3 Graph

implies, based on a doubling of total hours, twice as many engine starts, twice as many takeoffs, and twice as many landings. Due to these increases and others, an increased failure rate may result. Second, while the wing is now operating with twice as many aircraft, it is likely to still have the same number and variety of maintenance skills. The maintenance personnel, therefore, are required to double their level of effort. Intuitively, there is a limiting point where errors may begin to occur and where maintenance activities which would normally be accomplished are now deferred due to a lack of time. Thus, a third factor (BRKRT3) which can increase the overall failure rate based on an increase in total level of effort (HRSACT--hours actually scheduled) is needed. The proposed relationship of BRKRT3 to HRSACT is presented in Figure 29. As was the case with BRKRT1 and BRKRT2, maintenance personnel (11) suggested that data may be available to calculate a precise relationship of BRKRT3 as a function of HRSACT. Due, however, to time constraints and the relative unimportant nature of precise numerical values (5:57), Figure 29 was approximated as shown. Comments are now in order concerning the relationships shown in Figures 27, 28, and 29.

Aircraft failure rates are more sensitive to the number of sorties per aircraft per week than to either of the time factors (11). This assertion seems reasonable when one considers the stress placed on an aircraft during

the takeoff and landing phases of flight. BRKRT2, therefore, was scaled so as to produce the greatest measure of influence in failure rate calculations.

It was further suggested (11) that a wing's realized failure rate may be more sensitive to total level of effort than to strictly hours per aircraft per week. Again, the implications seem logical when it is recalled that the B-52 has an extremely long endurance capability. Hence, BRKRT3 was scaled to produce more influence in a wing's total failure rate than BRKRT1. One other point should be made prior to changing the topic of discussion.

It should be remembered that the construction of Figures 27, 28, and 29 were based on subjective judgements maintained by personnel (11) who work in the field. The experience of these personnel, however, would bias their judgements. Hence, relationships such as those indicated by BRKRT1, BRKRT2, and BRKRT3 should be reevaluated when applying this system to other environments.

It is indicated in Figure 26 and Equation #950 that an average break rate (BRKRTE) is determined by averaging BRKRT1, BRKRT2, and BRKRT3. BRKRTE is then randomized in a normal distribution. The randomizing of BRKRTE is necessary to replicate the uncertainties associated with failure rates. Finally, the randomized BRKRTE is placed within the limits of 0.1 and 0.75. Maintenance personnel (11) felt that some limits, such as those used, are needed for

two reasons. First, a wing will generally try to maintain one aircraft at all times in phase inspection and washing and lubrication. Also, there is usually at least one aircraft involved in major maintenance at all times. Hence, the average wing behavior is to usually maintain at least two aircraft in some type of major maintenance activity. System behavior is to have, on the average, six to seven aircraft available. Thus a lower limit of 0.1 would establish slightly over 0.5 aircraft in major maintenance. Such a result seems reasonable. Second, the higher limit of 0.75 was suggested as an arbitrary limit to further insure a replication of actual system behavior. It will be shown in future chapters, however, that this higher limit of 0.75 is never reached except when extreme conditions are externally introduced into the system. Then, management controls will slowly bring the system back to its normal operating state.

Figure 26 indicates that aircraft flow into the major maintenance level (INMX) is based on the controls imposed by ACRQMX. The flow out of this level is controlled by RQMXAC, however, and has yet to be discussed.

Loring personnel (11) indicated that an aircraft phase inspection normally requires approximately three days. Other major maintenance, however, can require anywhere from one day to many weeks. It was suggested that an average delay for major maintenance is approximately one week.

Hence, RQMXAC (Equation 790) allows aircraft to flow out of INMX in an average time of one week. System behavior, as will be shown in Chapter V, reinforces the validity of this choice. The next subpart of the Aircraft Availability Sector to be discussed is the flow of aircraft through the alert process.

The flow of a wing's aircraft through the alert cycle is presented in Figure 30. As indicated in this figure, the wing-level decision makers first determine the number of aircraft that are available to place on alert (ACAVLA) (11). ACAVLA (Equation #980) is determined by subtracting the number of aircraft requiring major maintenance (ACRQMX) from the total number of available aircraft (ACAVAL). The implicit policy captured in this structure is one of priority. Fulfilling alert requirements is first priority over all other activities (11).

Figure 30 further indicates that the actual number of aircraft placed on alert (ACONA) is also a function of the alert requirements (ALRTRQ), the number of operations crews available for alert (OPALRT), the number of aircraft that are already on alert (ACON), and the number of aircraft that have just been taken off of alert (ALRTAC). The decision process for calculating ACONA is presented in Equation #1000. The number of aircraft to be placed on alert is equal to ALRTRQ - ACON + ALRTAC, as constrained by aircraft and crew availability. Loring personnel (11) indicate

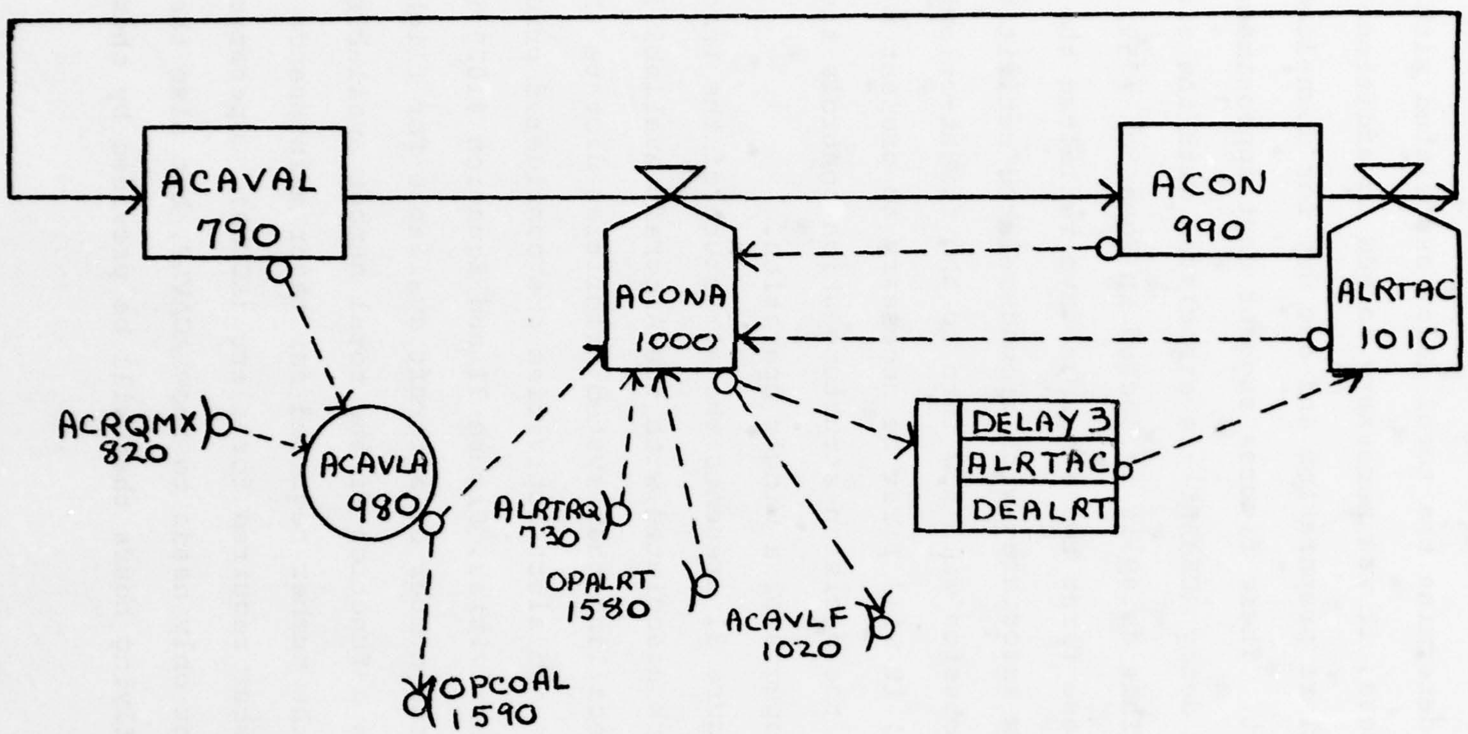

Fig. 30. Aircraft Availability Sector--Flow Diagram 2

that normally an aircraft will remain on alert for thirty days. To determine the total delay associated with the alert process, it was necessary to add an additional two days for alert preparation and one day for down-loading after alert. These figures suggest that approximately a 4.6-week delay (DEALRT) is associated with the alert process. This delay is reflected in Equation #750.

These first two subparts have reflected the aircraft flows associated with ground-related activities. As the discussion will now turn to the flight-oriented activities, it will first be necessary to present a discussion of the decision structure which controls the inflight aspects of a wing's operation.

Figure 31 presents the structure of the information network associated with the Aircraft Availability Sector. Recalling that system priorities dictate that maintenance and alert activities are considered prior to flying activities, Figure 31 and Equation #1020 indicate that the number of aircraft available for flight (ACAVLF) is a function of the total number available (ACAVAL), the number required for major maintenance (ACRQMX) and the number required for alert (ACONA). Operations, however, not only needs to know ACAVLF, but also the total number of flying hours that will be provided by these aircraft.

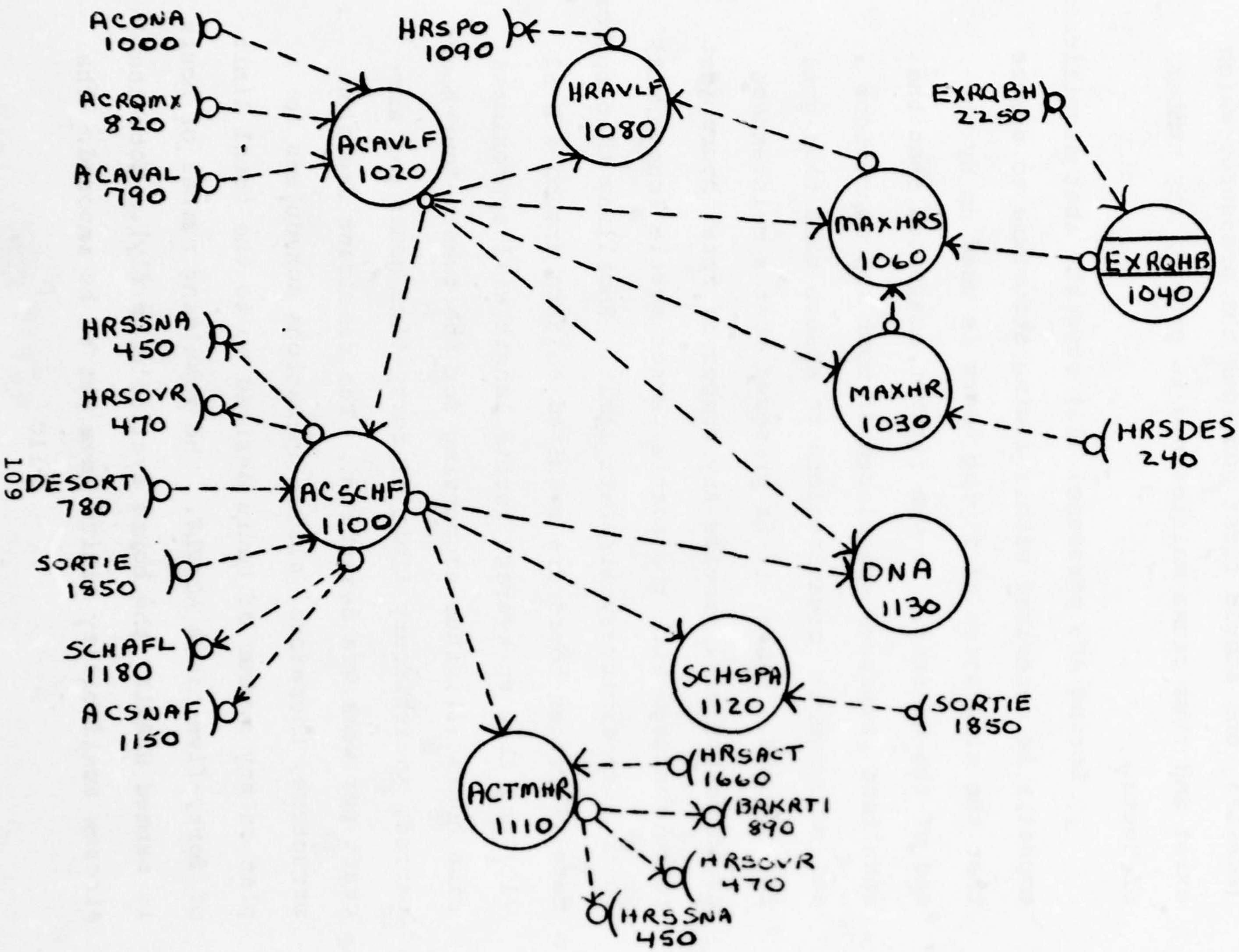

Fig. 31. Aircraft Availability Sector--Flow Diagram 3

In order to determine the total number of flying hours (HRAVLF) that maintenance will agree to provide based on a given number of aircraft available for flight (ACAVLF), one should first consider the pressures which exist and thus cause maintenance to provide any number of hours.

Loring AFB personnel (11) suggests that significant emphasis is generated within a wing structure to ensure that the allocation of flying hours is used up by the end of the quarter. It was further suggested that the resultant pressures are placed on both the operations and maintenance organizations to ensure that this goal is attained. Hence, it is proposed that a maintenance organization will provide any number of total hours (not to be confused with the sortie versus sortie length mix) up to some arbitrary aircraft limit. Recalling that approximately fifteen hours are required to turn around a B-52 (11) and that an average sortie length will approximate nine hours (1), thus accounting for one twenty-four-hour period, an arbitrary limit of forty-five hours per aircraft per week was designated. The resultant decision structure, therefore, allows operations schedulers to plan on any number of hours desired up to the total limit of forty-five times ACAVLF. The resulting number of hours is termed HRAVLF (the hours available to fly). Note that aircrew availability limits have yet to be imposed. The

minimum of HRAVLF and the previously discussed hours desired by the operations scheduler (HRSDES) resulted in HRSPO, again shown earlier.

There is, however, one other factor which can generate additional pressure on the maintenance organization to provide additional flying hours from ACAVLF (11). This additional pressure materializes if operations personnel are behind in the accomplishment of the assigned flying training requirements.

Loring AFB operations schedulers indicate that a desired level of flying training requirements remaining exists as does a desired level of flying hours remaining (DEHRMN) (1). When the difference between desired requirements remaining versus actual requirements remaining increases, pressure begins to build on the operations scheduler. It is felt that this pressure will continue to build until a point is reached where the executive wing staff will intervene. This intervention will take the form of a request to the maintenance organization to provide additional hours from ACAVLF thus allowing more requirements to be scheduled in the upcoming period. Loring personnel again felt that this point at which pressure is applied to maintenance is equivalent to four days requirements. In order to translate four days of flying activities into a specific number of requirements, several factors had to be considered.

The first factor to be considered when one attempts to convert four days of flying activities into a specific number of requirements is the total number of requirements levied. This total number of requirements should reflect both HHQ requirements and wing-directed requirements. Appropriate regulations (15:pp. 6-1 to 6-5; 7-1 to 7-3) indicate that a Loring AFB B-52 crew has approximately 391 requirements to accomplish per quarter. Assuming 20 crews assigned, this equates to 7820 requirements that should be accomplished by the end of the quarter. Dividing this total number of requirements per quarter by the number of weeks in the quarter and then, again, by five days in the work week, one determines that approximately 120 requirements should be accomplished each day. If this factor is multiplied by four days, it becomes apparent that the maintenance organization should begin to feel additional pressure when the crew force is approximately 480 requirements behind its desired accomplishment rate. As will be highlighted later, upon first realization that the requirements accomplishment rate is falling behind, the operations scheduler will start increasing requested sortie lengths up to a maximum of ten hours (1). If the difference between desired versus actual requirements remaining continues to increase above 480, then pressure will begin to be placed on maintenance to provide additional flying hours from ACAVLF. Equation #2250 calculates

the number of extra (above 480) requirements behind (EXRQBH), thus resulting in the additional pressure on maintenance.

Some means, however, had to be developed to translate the pressure generated by EXRQBH into an actual number of additional hours that are available. This conversion process is indicated in Figure 32 and Equation #1040.

Figure 32 indicates that the extra requirement hours behind (EXRQHB); hence, the additional number of flying hours that maintenance is pressured to provide; is a linear function of EXRQBH. The scaling for each axis of Figure 32 should be explained.

The scaling of the horizontal axis of Figure 32 is based on the maximum sortie length desired by an operations scheduler and an average number of sorties per day. To begin with, it was shown earlier that twenty B-52 crews may be required to complete approximately 7820 requirements per quarter. If this 7820 requirement is divided by the flying hour allocation, 1400 hours for example, it would be shown that approximately 5.6 requirements per hour must be accomplished. This requirements per hour factor must now be converted to one day's activity.

The maximum sortie length desired by an operations scheduler is ten hours (1). A SAC aircrew is only allowed to practice takeoffs, landings, and other traffic pattern activity for up to twelve hours from the time that the

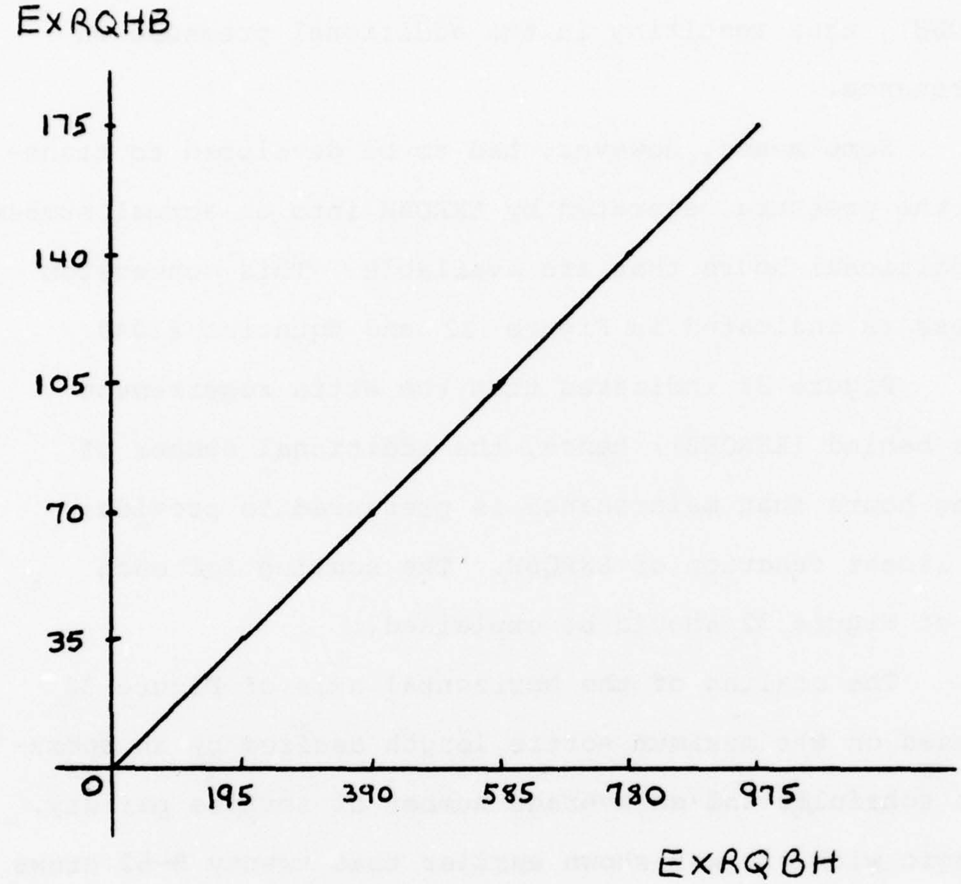

Fig. 32. EXRQHB Graph

crewmember reports for duty. Additionally, a crewmember is normally required to report for duty two hours prior to scheduled takeoff time. Considering the nine-hour flights which are common in B-52 operations and understanding that all traffic pattern activity is limited to the end of the mission due to gross weight limitations imposed on the aircraft, one can appreciate the maximum desired length of ten hours. Thus, Loring personnel (1) indicate that when an operations scheduler starts falling behind in requirements, an effort will be made to increase sortie lengths up to ten hours. If the ten-hour sorties are not sufficient (i.e., if the total number of requirements behind continues to increase above 480) to allow the scheduler to catch up, an effort will then be made to obtain additional hours for additional sorties. This is the purpose of EXRQHB in the system. With an average of 3.5 sorties per day (1) and a maximum length of ten hours per sortie, the scheduler has approximately 35 hours per day available. At the previously mentioned rate of 5.6 requirements per hour, then 195 extra requirements behind would equate to 35 hours of extra flying time needed. Hence, the horizontal axis of Figure 32 (EXRQBH) is incremented by 195 requirements while the vertical axis (EXRQHB) is increased by 35 hour increments. The calculated value of EXRQHB is divided by the number of aircraft available for flight (ACAVLF) and is subsequently added to MAXHR

to produce the total number of hours (MAXHRS) which are to be made available per available aircraft. This value of MAXHRS is multiplied by ACAVLF to produce HRAVLF, the total number of flying hours that are to be provided by maintenance. As indicated before, HRSPO is determined to be the minimum of HRSDES, the maximum number of hours desired by the operations scheduled strictly based on flying hours remaining, and HRAVLF, the maximum number of hours that maintenance will provide from available aircraft based on the pressures that exist.

The implicit policy associated with the HRSPO calculation needs to be reinforced. By calculating the minimum of HRSDES and HRAVLF, flying hours remaining ultimately becomes the controlling factor. For example, the crew force may be significantly far behind in the accomplishment of requirements. If, however, flying hours flown are consistent with desires, then only HRSDES will be scheduled. This fact further highlights the overriding executive-level policy of an even spreading of flying hours over all weeks of the quarter.

A final note concerning HRAVLF needs to be highlighted. As shown in Equation #1060, MAXHRS, and consequently HRAVLF, is still limited to forty-five hours per aircraft week. This value is a realistic physical limit and, as such, is consistent with the actual system.

Figure 31 and Equation #1100 indicate that the number of aircraft that are actually scheduled to fly (ACSCHF) is based on the number of sorties that are scheduled to fly (SORTIE), the desired number of sorties per aircraft per week (DESORT), and the number of aircraft available to fly (ACAVLF). DESORT, as shown in Equation #780, is valued at one. The net effect of this valuation is to attempt to fly as many different aircraft as there are sorties. It is realized, however, and is shown in Equation #1100, that the limiting factor restricting the number of aircraft scheduled to fly is that number of aircraft which are available. Hence, the result is to attempt to fly all that are available. Loring AFB maintenance personnel concurred with this philosophy (11).

The effort to fly all available aircraft stems from the discussion of BRKRTE. If an attempt is made to hold in-commission aircraft in reserve, the utilized aircraft are receiving increased use either in terms of sorties or hours or both. As was pointed out in the discussion of BRKRTE, the result would be to drive failure rates up. Then, less aircraft are again available which tends to perpetuate the increased failure rate. This ever-increasing failure rate provides the impetus, to the maximum extent possible, for flying all available aircraft.

Once the number of aircraft scheduled to fly (ACSCHF) is determined, a comparison with ACAVLF produces

the number of aircraft which will not be utilized (DNA) in the upcoming period. It is also possible to then determine the number of scheduled sorties per aircraft (SCHSPA) and the scheduled number of hours that each aircraft is to fly (ACTMHR). The highlighted variables of Figure 31 provide many additional inputs to other factors. These follow-on inputs will be addressed when the variables receiving the inputs are presented.

The next subpart of the Aircraft Availability Sector to be presented is the flow of aircraft through the no-fly level. The no-fly process is presented in Figure 33.

As shown in Figure 33, the number of aircraft which flow into the no-fly level (NOFLAC) is controlled by ACSNAF. Figure 33 further indicates that all controls implemented by ACSNAF are in response to the number of aircraft scheduled to fly (ACSCHF) and the randomized loss rate that the wing actually encounters (HRLRTR).

Equation #770 indicates that the delay associated with no-fly aircraft is a function of the constant 0.158. The constant represents the portion of a five-day week encompassed by a fifteen-hour preparation for flight and a four-hour delay to flight cancellation. Loring AFB personnel (1) indicate that efforts will normally be made for four hours after the scheduled takeoff time to repair

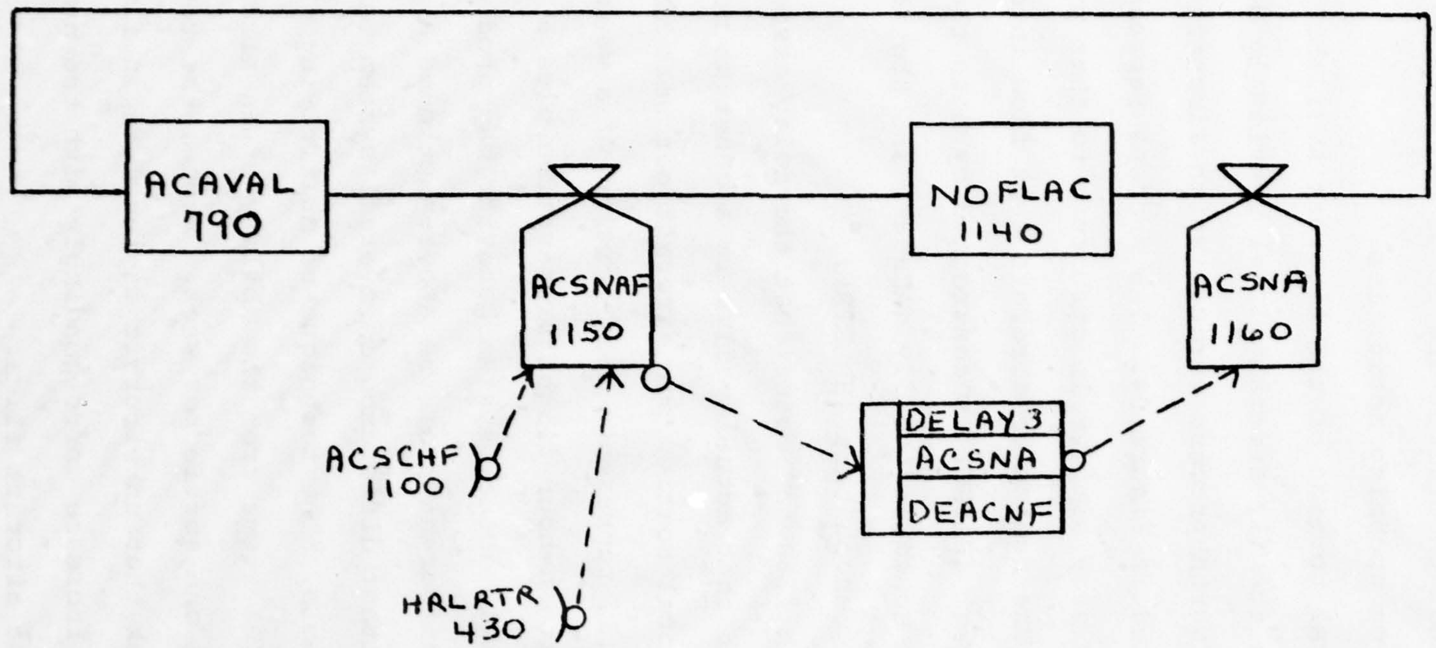

Fig. 33. Aircraft Availability Sector--Flow Diagram 4

a malfunctioning aircraft. After this time, it is usual practice to cancel the flight and focus maintenance resources back on upcoming activities.

The final portion of the Aircraft Availability Sector presents the fly-aircraft level previously discussed. This fourth process through which aircraft can flow is presented in Figure 34. The process represented in Figure 34 is very similar in structure to that presented in Figure 33. The number of aircraft that flow into the fly-aircraft level (FLYAC) is controlled by both the number of aircraft scheduled to fly (ACSCHF) and the actual loss rate a wing encounters (HRLRTR).

Equation #760 indicates that the delay associated with an aircraft that actually flys is a constant multiplied by the actual sorties per aircraft per week (ACTSPA). The constant, 0.2, represents that portion of a week that is used by a fifteen-hour flight preparation plus a nine-hour flight. While actual system behavior may produce sortie lengths different from the above-mentioned nine hours, the resultant difference in overall system behavior would be negligible. The technique of multiplying the constant by ACTSPA stems from the ability of an aircraft to fly more than one sortie per week. Hence, the total portion of a week that an aircraft is involved in flying activities will increase correspondingly with the number of times that the aircraft flies.

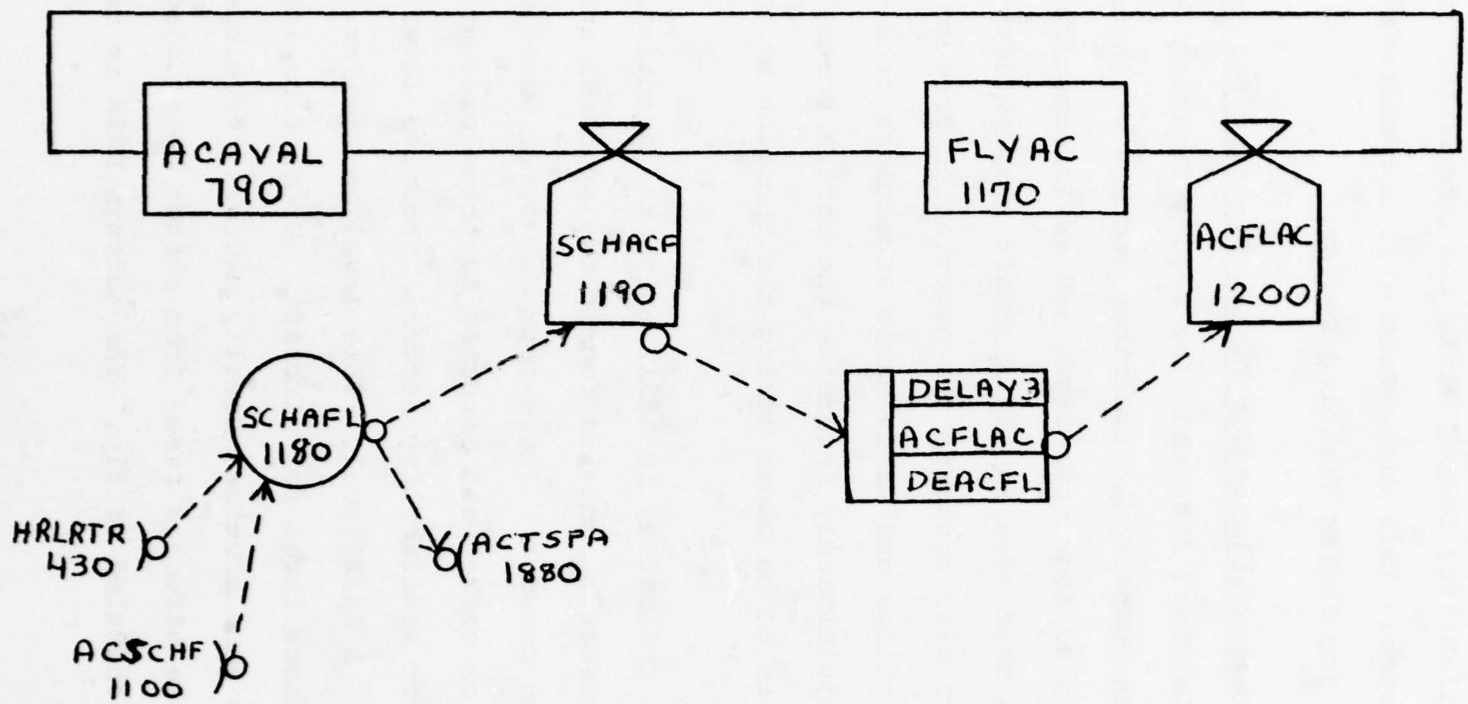

Fig. 34. Aircraft Availability Sector--Flow Diagram 5

The completion of this final subpart of the Aircraft Availability Sector marks the completion of the entire sector. This discussion will now address the Crews Available for Flying Training Sector.

Crews Available for Flying Training Sector

The Crews Available for Flying Training Sector is unique when compared to the other sectors of this system. In addition to four crew flows and an information network, similar to that seen in the Aircraft Availability Sector, this sector also contains the negotiation process through which operations and maintenance schedulers resolve conflicts and ultimately determine the sortie/sortie length mix which is to be flown during the upcoming scheduling period.

As indicated, in addition to the negotiation process, this sector contains four flows of crews and an information network. These four flows are based on five levels which correspond directly to those presented in the Aircraft Availability sector. The five levels include:

1. A DNIA level. This level is similar to the in-maintenance level for aircraft. Crews flow into this level when some problem, usually medical, develops and prevents the affected crews from either being placed on alert or scheduled to fly. The acronym DNIA is used to

imply that the crew is restricted to duty not including alert or flying.

2. An on-alert level. This level corresponds directly to the on-alert level for aircraft. Crews flow into this level as they are assigned to alert duties.

3. A no-fly level. This level directly compares with the no-fly level of the Aircraft Availability Sector. Crews flow into this level when they are scheduled for, and consequently prepare for, flight, but ultimately will have the flight cancelled.

4. A fly-level. This level is again directly analogous to the fly-level for aircraft. Crews flow into this level when they are scheduled for, and ultimately will participate in, an inflight training mission.

5. An available-level. This level contains the available crews who have completed their assigned activities and have not yet been reassigned to new tasks.

The development of the Crews Available for Flying Training Sector will be presented in a six-part format. The four crew flows and the information network will be presented in a manner similar to the Aircraft Availability Sector. The negotiation process, however, is a focal point for wing operations and, therefore, will be presented first.

The negotiation process that occurs between operations and maintenance schedulers is presented in Figure 35.

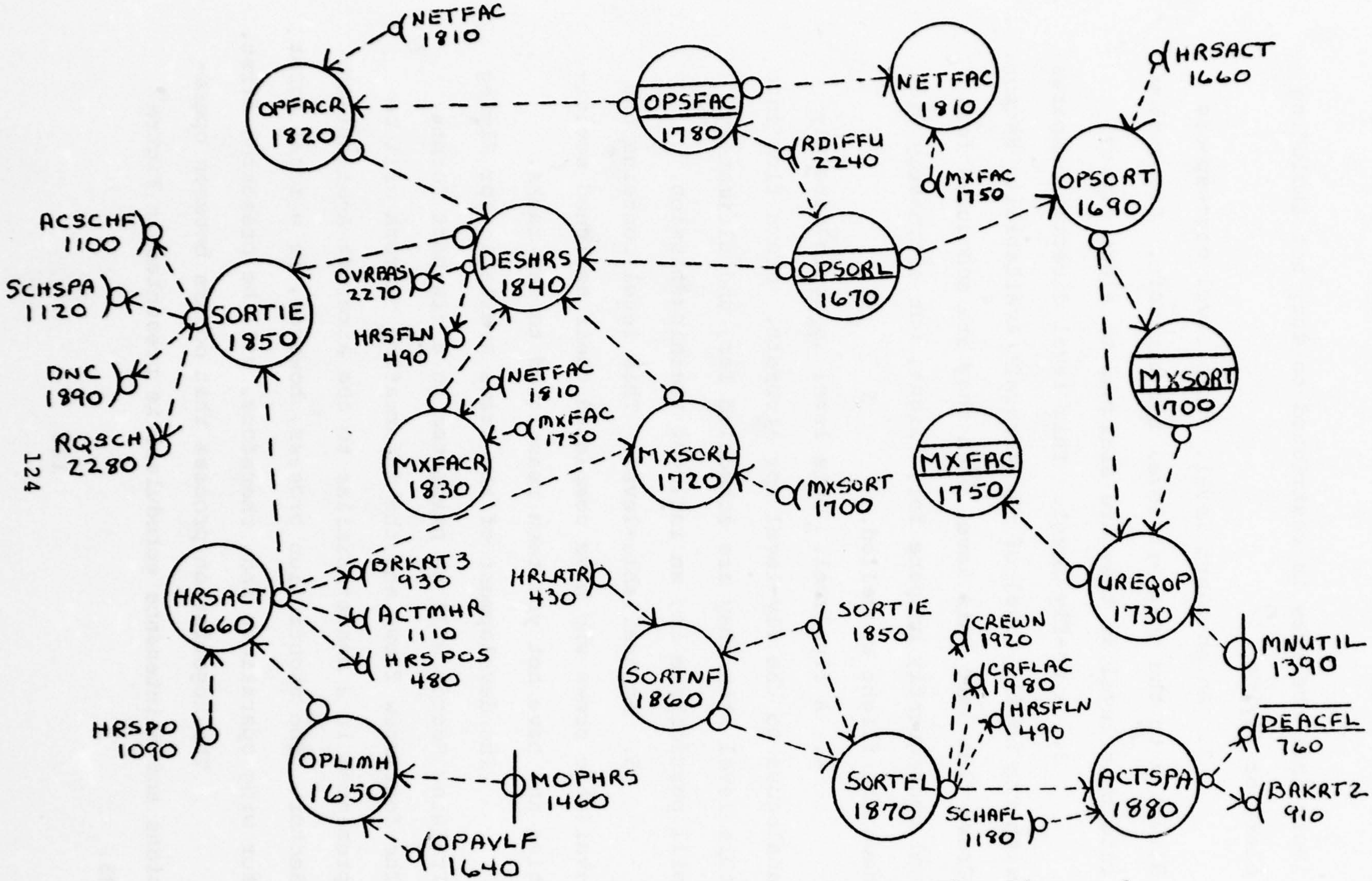

Fig. 35. Crews Available for Flying Training Sector--Flow Diagram 1

As indicated in earlier discussions, the pressures which are generated due to a differential in actual flying hours remaining (FHRRMN) versus desired flying hours remaining (DEHRMH) are applied directly to both the maintenance and operations organizations. If no pressure is generated due to flying hours, then it is felt (1; 11) that the primary pressures that influence a wing's scheduling process stem from operations crew's requirements. As mentioned earlier, a desired rate exists for the accomplishment of flying training requirements. If the rate at which requirements are accomplished falls behind that which is desired, then pressures begin to build on the operations scheduler.

When an operations scheduler enters the negotiation process in order to determine, with the maintenance scheduler, the sortie/sortie length mix that is to be scheduled for the upcoming period, it is likely that each scheduler is making requests based on perceived needs rather than actual needs (1; 11). For example, the operations scheduler may feel that longer sorties are needed in order to provide an airborne crew more time to accomplish requirements. The operations scheduler will advocate longer (up to a maximum of ten hours) sorties if the requirement accomplishment rate is less than desired. Similarly, this scheduler may remember that last quarter ended with a certain quantity of requirements remaining unaccomplished. Hence, when the

negotiation process is entered, the request for longer sorties could be based on an expectation of future needs as opposed to current needs.

Figure 35 indicates that the variable RDIFFU is an initiating factor in the negotiation process. This variable represents the scheduler's perception (or memory) of the flying training requirement differential (actual remaining versus desired remaining). As will be shown, RDIFFU generates some perceived amount of pressure that the operations scheduler will respond to. This scheduler will make initial requests based on this perceived pressure. Based on these initial requests from the operations scheduler, pressure will develop on the maintenance scheduler. The pressures felt by the maintenance scheduler result from the level of effort that would be required of the maintenance organization if all of operations' requests were fulfilled. It is the resultant weighing of pressures that captures the essence of the negotiation process (1; 11). If the operations scheduler is under a large amount of pressure due to a significant backlog of unaccomplished flying training requirements and yet the requests of maintenance precipitate an even larger amount of pressure on the maintenance scheduler, then it can be expected that negotiation outcomes will fall more in favor of the maintenance scheduler than the operations scheduler. Thus, the negotiations, as indicated, are a balancing of the pressures and the organization under the largest relative amount

of pressure will obtain the more favorable outcomes. With an understanding of the nature of the negotiation process, one can appreciate the importance of RDIFFU.

While RDIFFU originates in the Flying Training Requirements Sector, the significant influence which it maintains over the negotiation process suggests that it be addressed at the present time. RDIFFU, as shown in Equation #2240, is the result of exponentially smoothing the flying training requirement remaining differential (RDIFF--Equation #2200). The period over which this information is smoothed is classified as the scheduler's memory (SCHMEM). As shown in Equation #2210, the scheduler's memory varies based on the number of weeks remaining in the quarter (WKSREM).

Loring AFB schedulers (1) indicate that concern is greatest for past accomplishment rates during the earlier portions of the quarter. As the quarter progresses, however, the focus of attention becomes more directed toward the currently existing RDIFF. In order to quantify this changing focus of attention, Figure 36 was developed.

Figure 36 indicates that when negotiating for the first weeks activities, the operations scheduler has in mind the smoothed RDIFF which has resulted over the past eight weeks. As the quarter progresses, however, the emphasis is placed more on the currently existing requirement differential. Thus, during the last few weeks

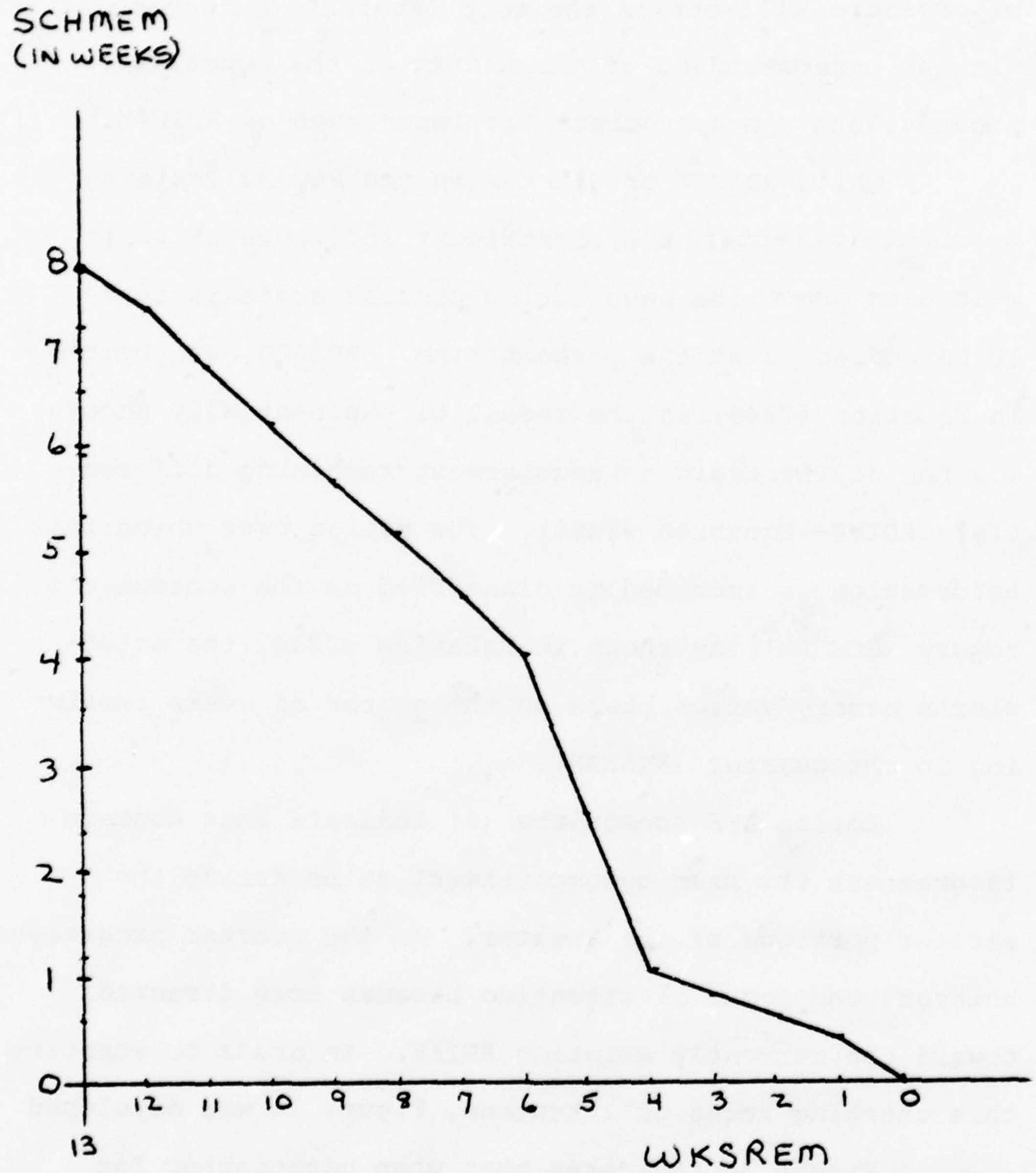

Fig. 36. SCHMEM Graph

of the quarter, the operations scheduler is focusing almost entirely on the current RDIFF and, hence, is responding to actual pressures as opposed to perceived pressures. Again, the variable used to indicate this changing focus of attention is RDIFFU.

Figure 35 shows that the number of hours actually scheduled (HRSACT) is a function of HRSPO and the number of hours available from operations crews (OPLIMH). HRSPO was previously indicated to be the minimum of the hours desired to provide an even spreading of the wing allocation over the weeks of the quarter and the hours that maintenance will provide based on aircraft availability. The maximum number of hours that can be flown by an aircrew is 125 hours in the last 30 days (1). This limit equates to 29.1 hours per week. Thus, the maximum number of hours that can be provided by operations crews is equal to the number of available crews (OPAVLF) times the limit of 29.1 hours per week (MOPHRS). The number of hours actually scheduled is, therefore, the minimum of HRSPO and OPLIMH. Once the number of hours to actually be scheduled (HRSACT) is determined, the negotiations for the sortie/sortie length mix can begin.

The process revealed in Figure 35 indicates that a certain amount of pressure will be placed on the operations scheduler (OPSFAC) by RDIFFU. As a result of this pressure, the operations scheduler will request a certain

sortie length (OPSORL). Based on OPSORL and the previously known HRSACT, the associated number of sorties being requested by operations (OPSORT) is calculated. As a result of the requested sorties, two other interactions occur.

Maintenance personnel (11) indicate that the pressure generated with the maintenance organization is primarily a function of the number of sorties that must be provided. As the number of sorties that are to be provided increases, similar increases in the total level of effort required by the maintenance also occurs. As was indicated (11), however, there does exist a number of sorties which maintenance will agreeably provide up to with little or no discussion. Loring personnel, however, were uncertain as to what this number should be. The question, therefore, addressed the problems associated with providing thirteen sorties. It is generally felt (11) that thirteen sorties would usually cause no problems; however, fourteen may. Figure 37, therefore, resulted.

Figure 37 indicates that the maintenance organization will willingly provide up to thirteen sorties, based on operations' requests, above which, however, bargaining power or pressures will be generated. Thus, any operations request for thirteen sorties or less will be honored by maintenance with little hesitation. Any requests for additional sorties, however, will have to be negotiated.

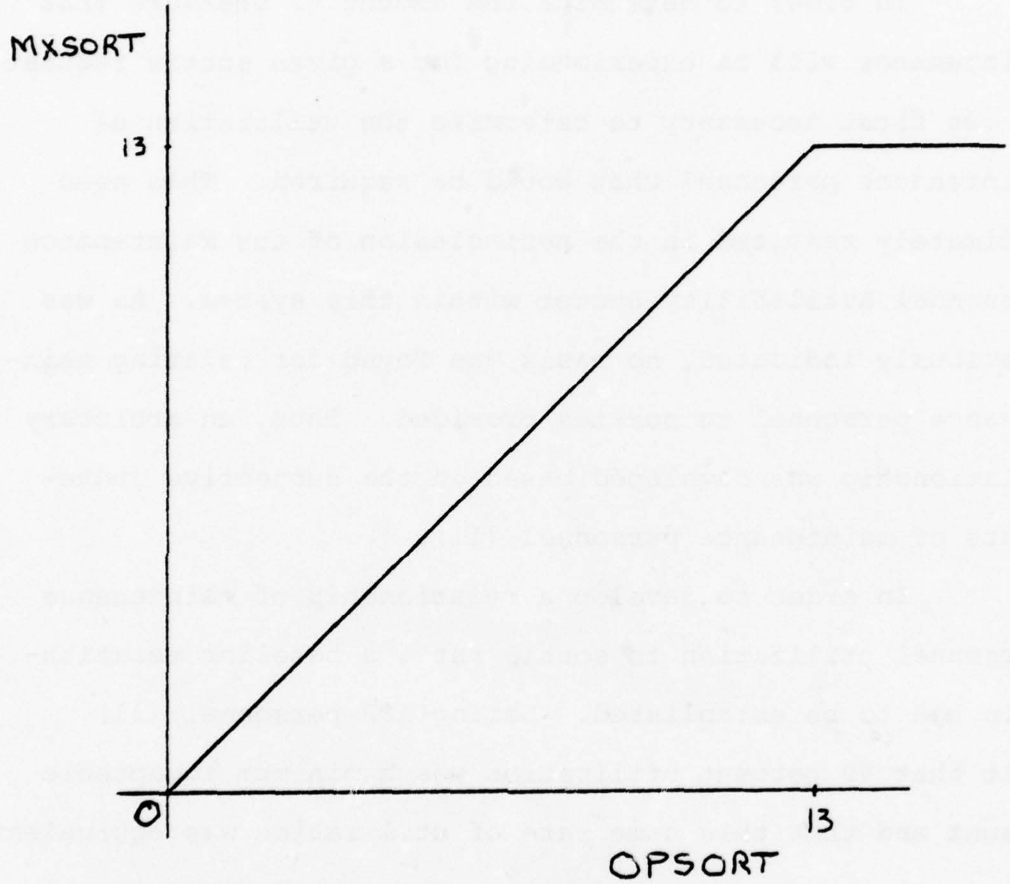

Fig. 37. MXSORT Graph

Concurrent with the determination of MXSORT is the calculation of the amount of pressure felt by the maintenance organization as a result of the operations sortie request.

In order to determine the amount of pressure that maintenance will be experiencing for a given sortie request, it was first necessary to determine the utilization of maintenance personnel that would be required. This need ultimately resulted in the noninclusion of the Maintenance Personnel Availability Sector within this system. As was previously indicated, no basis was found for relating maintenance personnel to sorties provided. Thus, an arbitrary relationship was developed based on the subjective judgements of maintenance personnel (11).

In order to develop a relationship of maintenance personnel utilization to sortie rate, a baseline relationship had to be established. Loring AFB personnel (11) felt that 60 percent utilization was a minimum acceptable amount and that this same rate of utilization was equivalent to a minimum pressure condition. When asked to estimate the number of evenly spaced sorties that would be associated with this given utilization rate, it was indicated (11) that approximately thirteen sorties could be expected. Hence, the sortie/utilization baseline for this research was established at 60 percent utilization and thirteen sorties. Equation #1730 therefore indicates that all sortie

requests (by operations) over and above thirteen will result in increased utilization of maintenance personnel.

This requested utilization is then translated by the maintenance scheduler into a perceived amount of pressure that the maintenance organization would be operating under should the operations request be honored. The translation process is indicated in Figure 38.

As shown in Figure 38, a minimum pressure of .1 is believed to exist for any requested utilization up to 60 percent, which is assumed to the equivalent to thirteen sorties. As shown, however, increased utilization requests would result in an increased level of pressure levied on to the maintenance organization. Figure 38 further indicates that an operations request of 80 percent utilization will result in a pressure factor of one. This scaling of pressure seemed consistent with the judgements of maintenance personnel (11).

These pressures, OPSFAC and MXFAC, are rescaled, based on the NETFAC equation (Equation #1810), to allow all pressures involved to sum to one. These rescaled pressures, now termed OPFACR and MXFACR, can be considered as bargaining power. The maintenance and operations schedulers each possess some measure of bargaining power; operations based on RDIFFU (the perceived requirements differential based on the scheduler's memory), and maintenance based on the personnel utilization that would be required

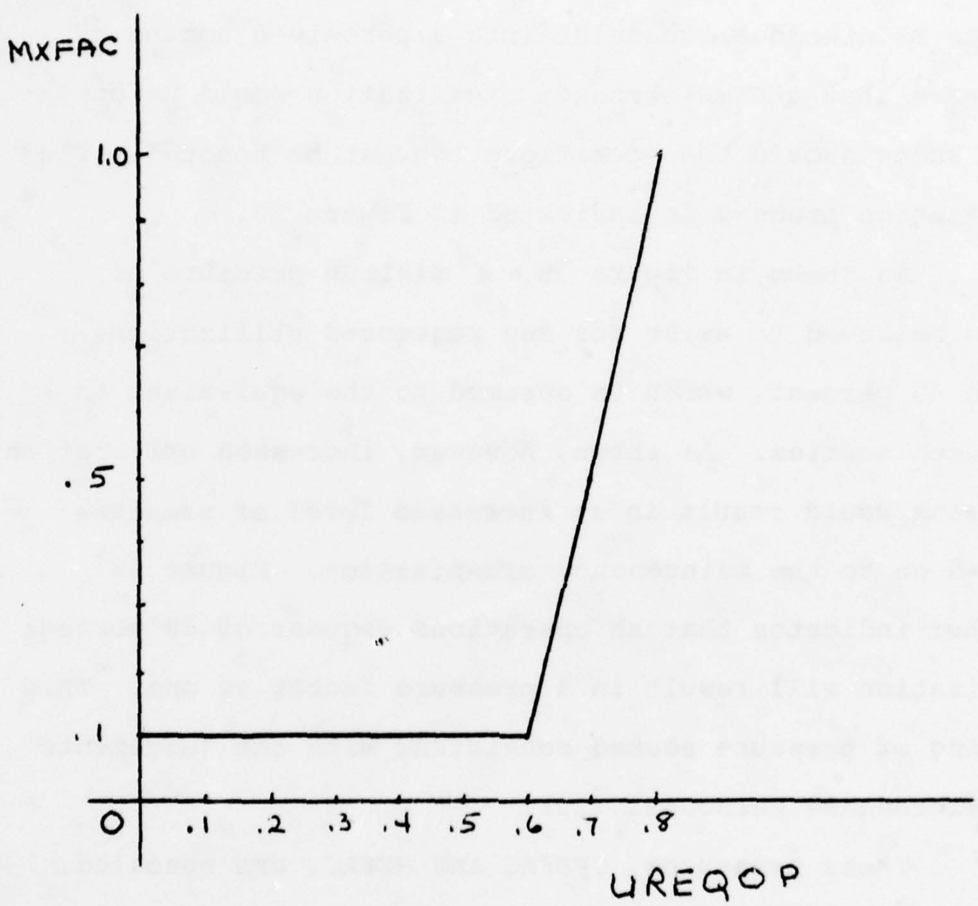

Fig. 38. MXFAC Graph

to fulfill operations' requests (UREQOP); with which the sortie/sortie length mix will be determined for the upcoming period.

It is indicated in Figure 35 and Equation #1840 that the negotiated sortie length (DESHRS) is based on the lengths desired by each organization and their respective bargaining powers. The negotiated number of sorties to be flown (SORTIE) therefore are determined by dividing DESHRS into the number of hours that are actually to be scheduled (HRSACT). Thus, the negotiation process is complete.

Included in the structure presented in Figure 35 is the determination of the number of scheduled sorties that ultimately do not fly (SORTNF) and the resultant number that do fly (SORTFL). Also shown is the determination of the actual number of sorties per aircraft (ACTSPA) that will be flown during the week. The calculation of ACTSPA is necessary due to current maintenance policy.

Loring AFB maintenance personnel (11) indicate that the scheduled number of sorties per aircraft (SCHSPA) may differ from the actual number that are flown. When a scheduled flight is cancelled due to an aircraft malfunction, an effort will be made to repair the aircraft (11). If the malfunction, however, drives the aircraft into major maintenance, then all sorties scheduled for that aircraft would be affected. An effort will be made

to utilize the remaining available aircraft to fly all scheduled sorties (11). If this effort is successful, then the actual number of sorties that each aircraft flys will be increased over SCHSPA.

With these final comments of Figure 35 complete, it is now possible to address the remaining parts of the Crew Availability for Flying Training Sector.

It can be recalled that the Crews Available for Flying Training Sector contained, in addition to the negotiation process, six other subparts which were similar in nature to the Aircraft Availability Sector. These other subparts included an information network, a level of crews incapable of being placed on alert or scheduled to fly, a level of crews on alert, a level of crews involved in no-fly activities, a level of crews in flying activities, and a level of available crews. The discussion of these remaining subparts will begin with the crews that cannot be scheduled for alert or flight.

The flow of crews through the non-alert, non-flying level is presented in Figure 39. This figure indicates that the number of crews to be placed in a non-alert, non-flying status (DNIA) is equal to a percentage of the operations crews that are available. The rationale for taking a percentage of the available crews and placing them in DNIA status is similar to that presented for aircraft requiring maintenance. While crews

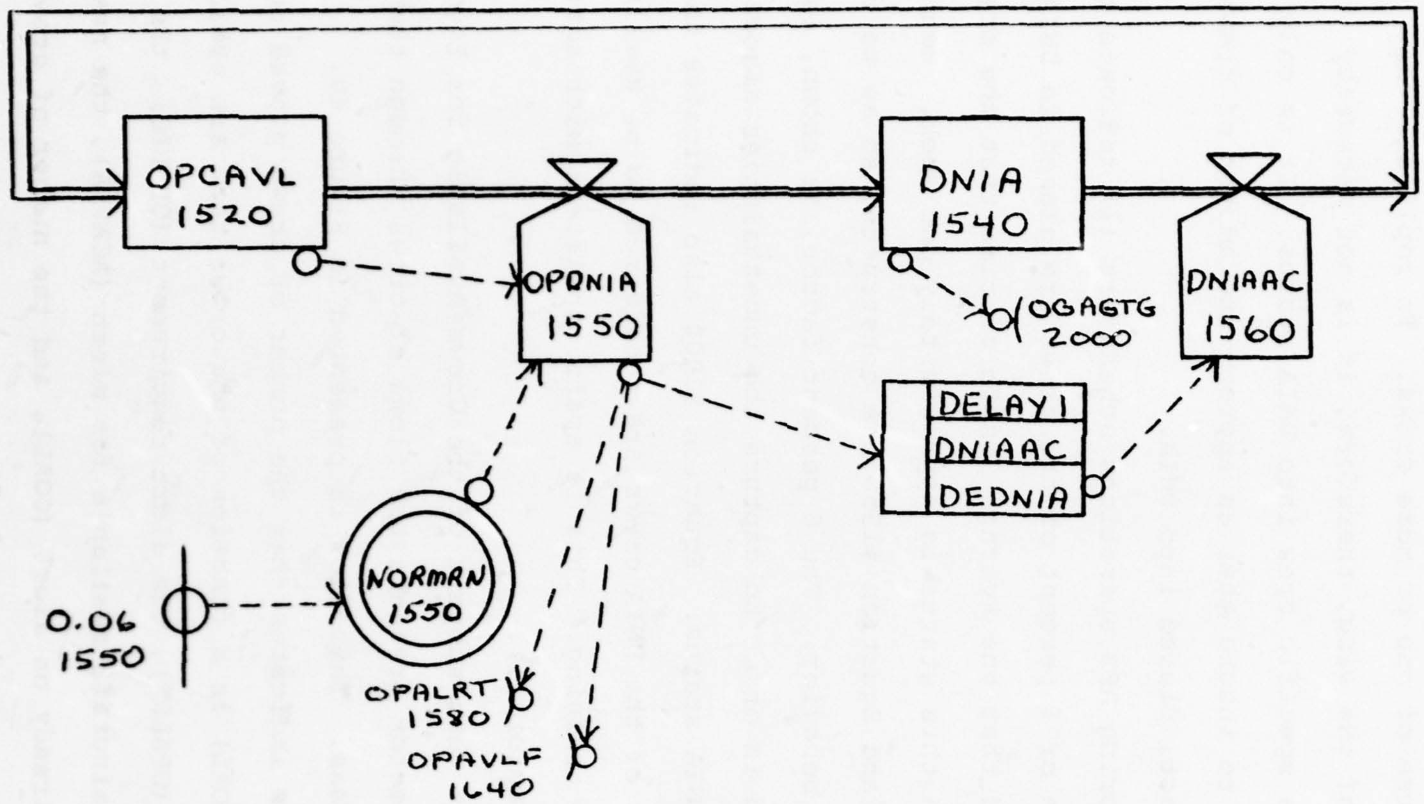

Fig. 39. Crews Available for Flying Training Sector--Flow Diagram 2

may actually be placed in a DNIA status without becoming available, the net effect on the system is that it has lost the use of one or more crews. To replicate the behavior of the wing, therefore, it is not necessary to place a specific crew into DNIA status. It is only necessary to insure that an appropriate amount of crews are, in fact, placed into DNIA.

Loring AFB operations schedulers (1) indicate that an average of 6 percent of the crews are placed in DNIA status and that the average length of time that the crew remains in this status is approximately one week. Hence, Figure 39 and Equation #1550 are constructed so as to replicate this behavior. The 6 percent factor, as shown, is randomized in order to capture the uncertainties associated with the DNIA status. Equation #2000 also indicates that 95 percent of the DNIA crews are considered to be available for ground training. This is again consistent with actual system behavior (1).

The next subpart of the Crews Available for Flying Training Sector presents the flows of crews through the alert process. This flow is presented in Figure 40. This figure indicates that the number of crews placed on alert (OPCOAL) is a function of the crews that are available for alert (OPALRT), the alert requirement (OPALRQ), the number of aircraft available for alert (ACAVLA), the number of crews already on alert (COAL), and the number of crews

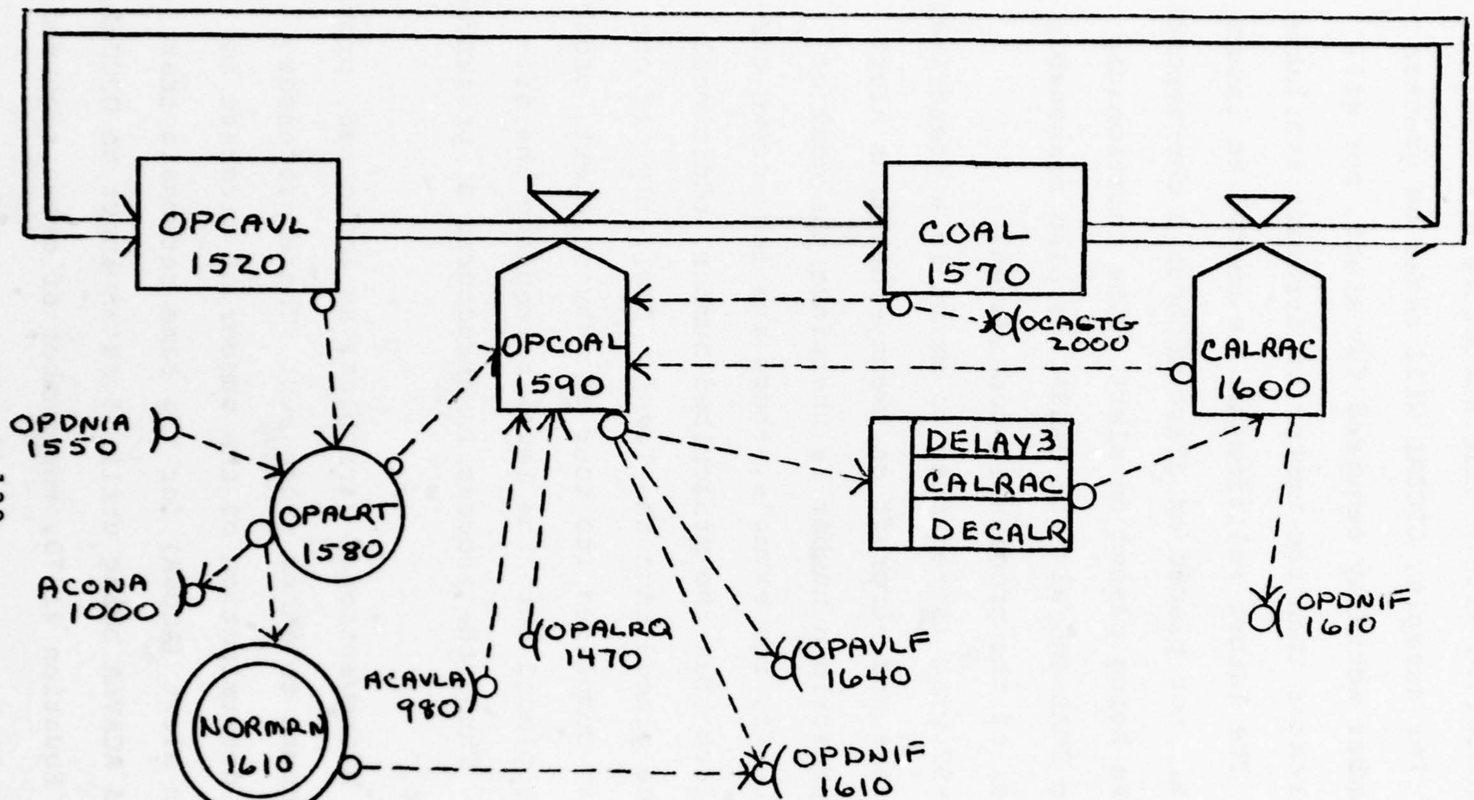

Fig. 40. Crews Available for Flying Training Sector--Flow Diagram 3

that have just been taken off alert (CALRAC). The relationships contained within this structure are seemingly intuitive. For example, OPCOAL will never be greater than the number actually required for alert, nor will OPCOAL be greater than the number of aircraft available for alert. The latter relationship is needed to insure that crews are not placed on alert without a corresponding aircraft also being placed on alert. The relationship of OPCOAL to COAL and also to CALRAC is also reasonable when the goal of the process is considered.

A B-52 wing is required to maintain a prescribed number of crews and aircraft on twenty-four-hour alert (1). This prescribed number is therefore the goal of the process. If, for example, there are less crews currently on alert than the prescribed number, additional crews will be placed into the level. Similarly, if one crew has just completed its tour of duty on alert, another crew must be placed into the level to replace the off-going crew. Thus, the process is structured as presented in Figure 40.

The aforementioned variables, as indicated, provide follow-on inputs to other processes. These processes include the determination of the number of aircraft to be placed on alert (ACONA) for the same rationale that precipitated ACAVLA being utilized as an input to OPCOAL. As shown in Equation #1470, the number of crews required

on alert in this system is four. The next subpart of the Crews Available for Flying Training Sector that will be presented is the information network, aside from the negotiation process, contained within. The information network contained in this sector is presented in Figure 41.

The process presented in Figure 41 indicates that the number of crews that are temporarily disqualified from flying activities (OPDNIF), usually for medical reasons, is a function of the crews available for alert (OPALRT), the number of crews placed on alert (OPCOAL), and the number of crews who have just been taken off alert (CALRAC). This relationship was developed for the following reasons.

Crews can be assigned to alert duties even though they may be temporarily restricted from flying duties for medical reasons (DNIF). If the medical problem had been other than minor in nature, the crew would have been placed in DNIA status (1). Thus, the total number of a wing's DNIF crews may include both crews on alert and those participating in other non-flying duties. When considering the flows of crews through the system, however, it must be acknowledged that those DNIF crews that are participating in alert duties would not be available for flying duties even if the medical problem did not exist. Thus, the only restriction on available crews caused by

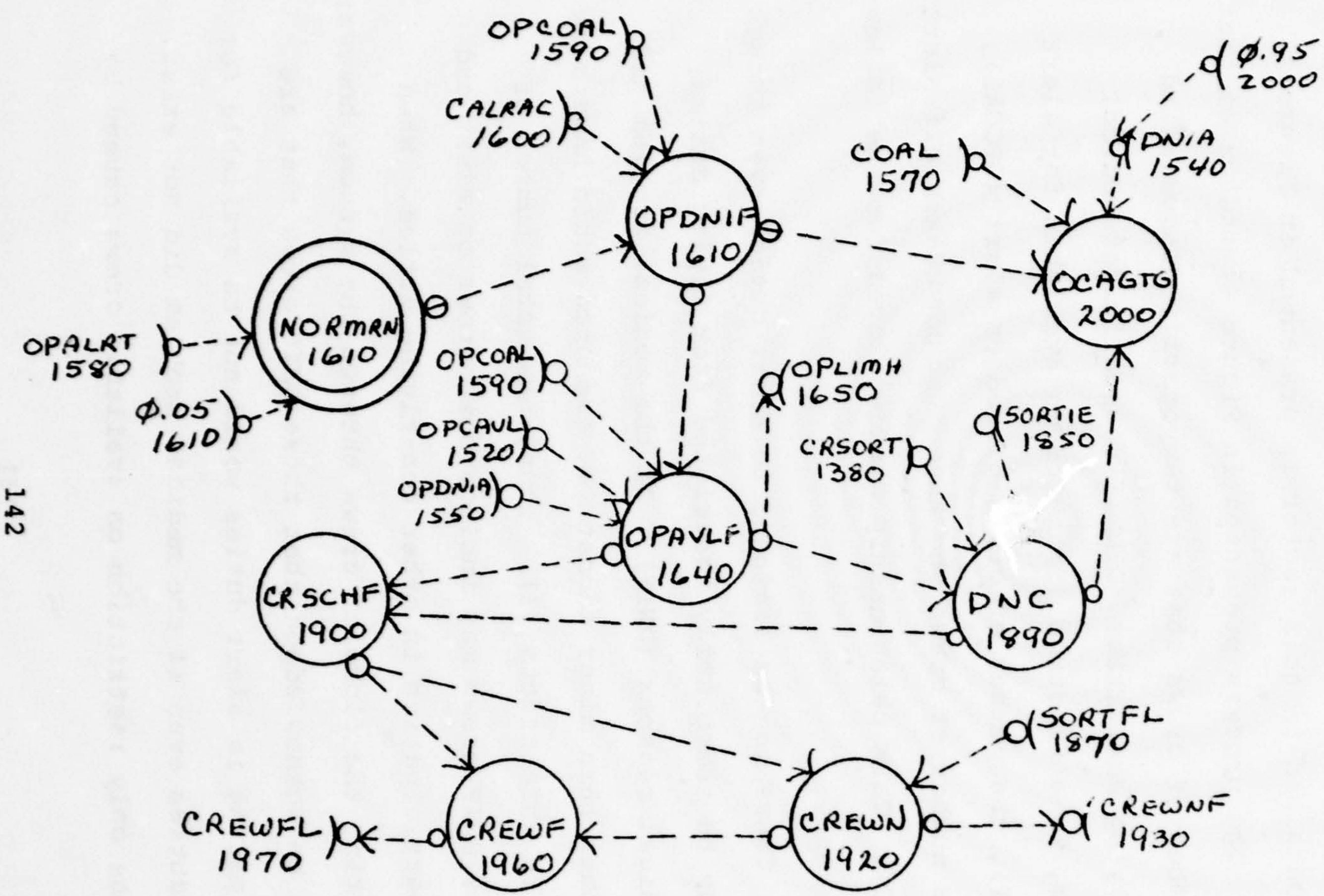

Fig. 41. Crews Available for Flying Training Sector--Flow Diagram 4

a DNIF status is on those crews that are available after alert requirements are met.

Loring AFB schedulers (1) indicate that it is not uncommon to experience an average of 5 percent of the crews after alert being DNIF. This percentage, as shown in Figure 41, is randomized in a normal distribution to account for the uncertainties associated with this process. This randomized value is then applied, as shown in Equation #1610, to the number of crews that were available for alert (ACAVLA) minus those that were placed on alert (OPCOAL) plus those that just completed alert (CALRAC). The resulting value is the number of DNIF crews that will be present in the wing for the upcoming week.

It is further indicated in Figure 41 that the number of crews available to fly is a function of OPDNIF, OPCOAL, the total number of crews that were initially available (OPCAVL), and the number of crews that were placed in DNIA status (OPDNIA). Crews available to fly (OPAVLF) are those crews remaining when all of the above categories are subtracted from OPCAVL. The number of crews that have no scheduled flying activities can be determined by first considering the policy associated with crew's flights. CRSORT, the desired number of sorties per crew per week, represents the associated management policy. A primary objective of the operations scheduler is to fly as many crews as possible (1). This policy,

in effect, spreads the week's activity over as many crews as possible in hopes of maintaining an overall higher level of crew proficiency (1). As is therefore shown in Equation #1380, CRSORT is assigned a value of one. Thus, the number of crews scheduled to fly (CRSCHF) will, depending on OPAVLF, be equal to the number of sorties scheduled (SORTIE).

Additional policy insights provided by operations schedulers (1) indicate that if a sortie is cancelled, an attempt will be made to spread the remaining sorties over all previously scheduled crews. Thus, Equation #1920 is structured as shown. A comparison of CRSCHF with CREWN will indicate the number of crews that actually fly (CREWF). The next subpart of the Crews Available for Flying Training Sector presents the flow of crews through the no-fly level.

The flow of crews through the no-fly level is shown in Figure 42. As previously indicated, the number of crews that enter the no-fly level (NFCREW) is strictly controlled by CREWN. The delay factors associated with crew flows through either the fly or no-fly levels are identical.

Operations schedulers (1) indicate that once a crew is scheduled to fly, and the crew has already entered the mission planning phase of preparation, it is extremely difficult to use that crew for some other activity should the flight be cancelled. The delay factor associated

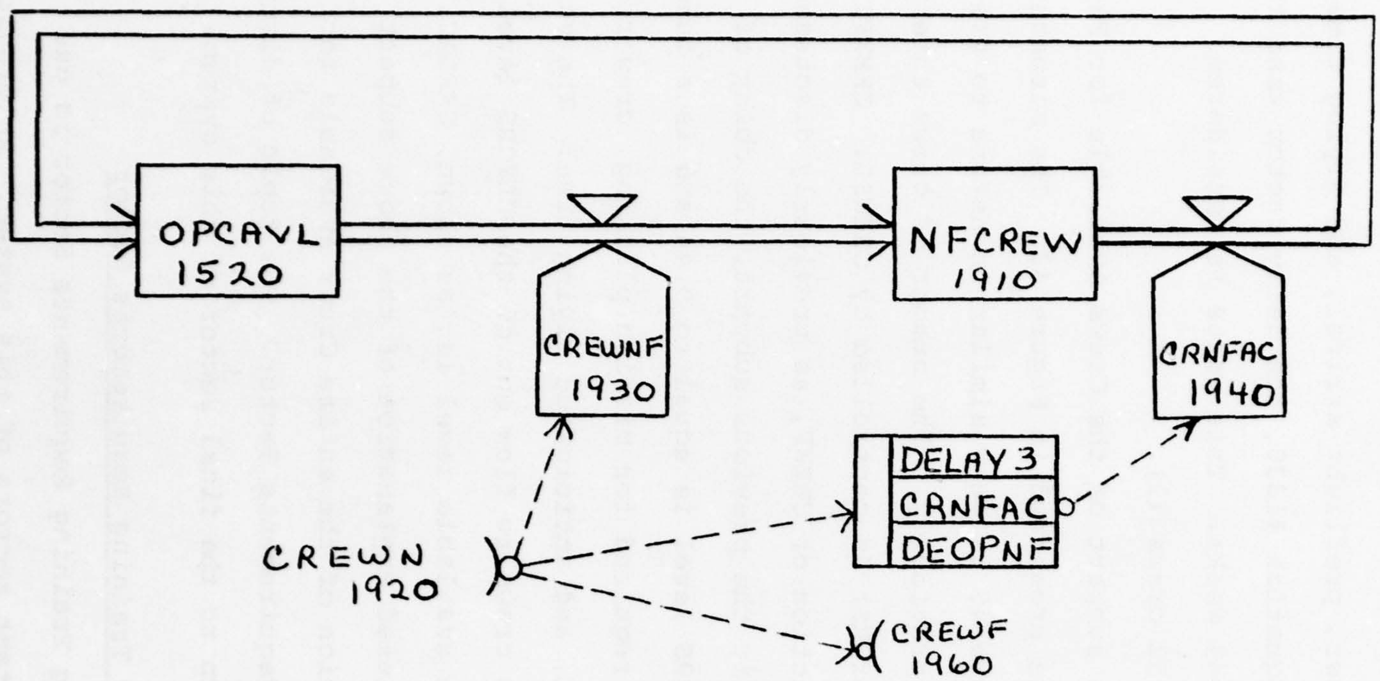

Fig. 42. Crews Available for Flying Training Sector--Flow Diagram 5

with crew flows through this and the fly level is determined by adding the number of hours associated with mission planning, crew rest, preflight arrival, and flying time. As indicated in Equation #1330, the delay factor used in this system is 0.44 weeks. This value is considered reasonable for B-52 crews (1).

The final subpart of the Crews Available for Flying Training Sector is presented in Figure 43. The structure presented in Figure 43 is very similar in nature to processes presented previously. The number of crews entering the fly-level (FLYCRS) is controlled by CREWFL. CREWFL, in turn, is a function of CREWF, as previously discussed. As was suggested in the previous subpart, the delay of crews in the FLYCRS level is equal to 0.44 and is a function of the time required for mission planning, crew rest, preflight arrival, and anticipated flying time. The variable which allows crews to flow out of the FLYCRS level and back into the available level is, as shown, CRFLAC.

The completed explanation of the above subpart marks the completion of the entire Crews Available for Flying Training Requirements Sector. The topic of discussion will now turn to the final sector of this system.

Flying Training Requirements Sector

The Flying Training Requirements Sector is one of the most important sectors of this system. As previously

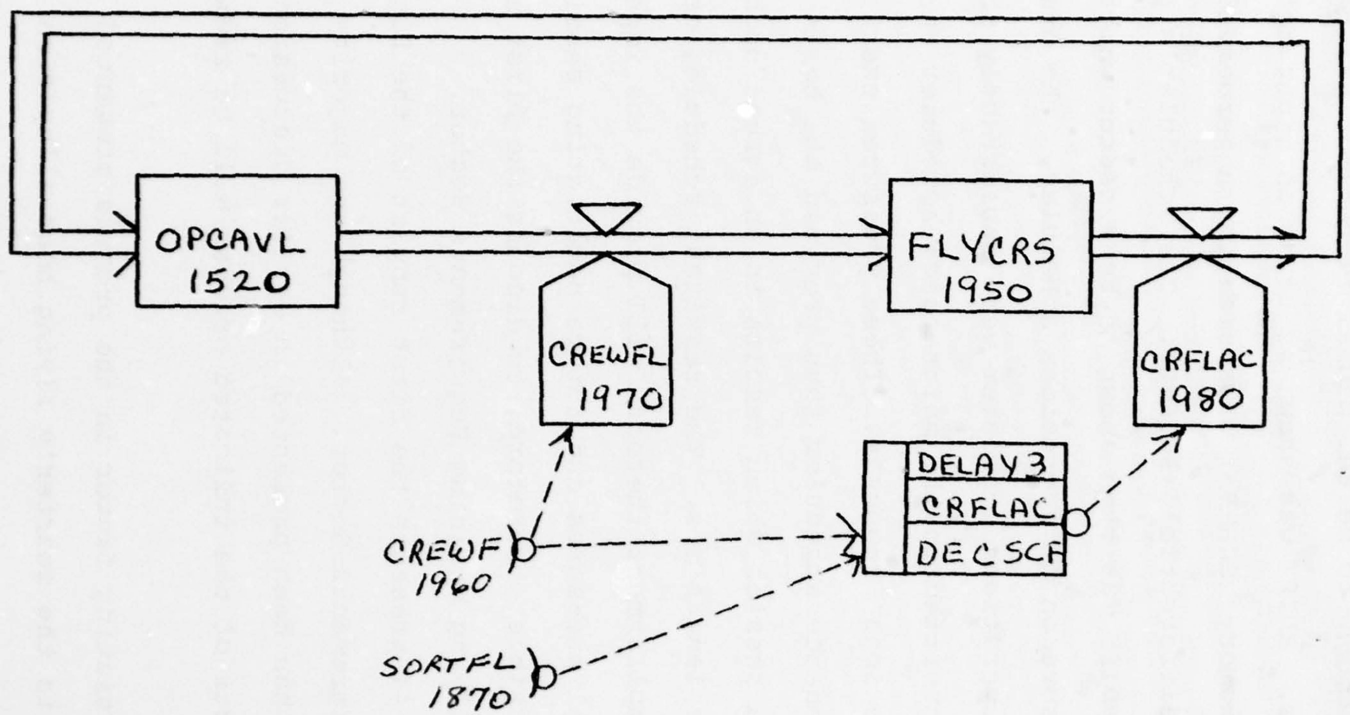

Fig. 43. Crews Available for Flying Training Sector--Flow Diagram 6

shown, the difference (RDIFF) between actual requirements remaining (FRQREM) and desired requirements remaining (DERQRM) is thought to be the causal factor for all negotiation results. RDIFF was shown as being an input to the scheduler's memory (SCHMEM) thus creating a perceived requirement differential (RDIFFU). The scheduler's perceptions of RDIFF was then shown to be a factor which creates pressure on the operations scheduler. The pressures felt by the operations scheduler were subsequently shown as being transmitted to the maintenance scheduler in the form of operations' requests. These pressures exerted on the maintenance scheduler thus provided the basis for a negotiation session which results in an agreed upon sortie/sortie length mix. The resultant schedule, or lack of accomplishment thereof, will provide the impetus for additional pressures and future negotiating sessions. It is now possible, therefore, to discuss the first subpart of the Flying Training Requirements Sector.

Figure 44 presents the first subpart of the Flying Training Requirements Sector. Although the majority of Figure 44 has been presented in earlier discussions, several aspects of the indicated process will be reemphasized.

The initiating factor in the process presented in Figure 44 is the quarterly flying hour allocation (FRQMNT). As shown, this allocation is pulsed into the

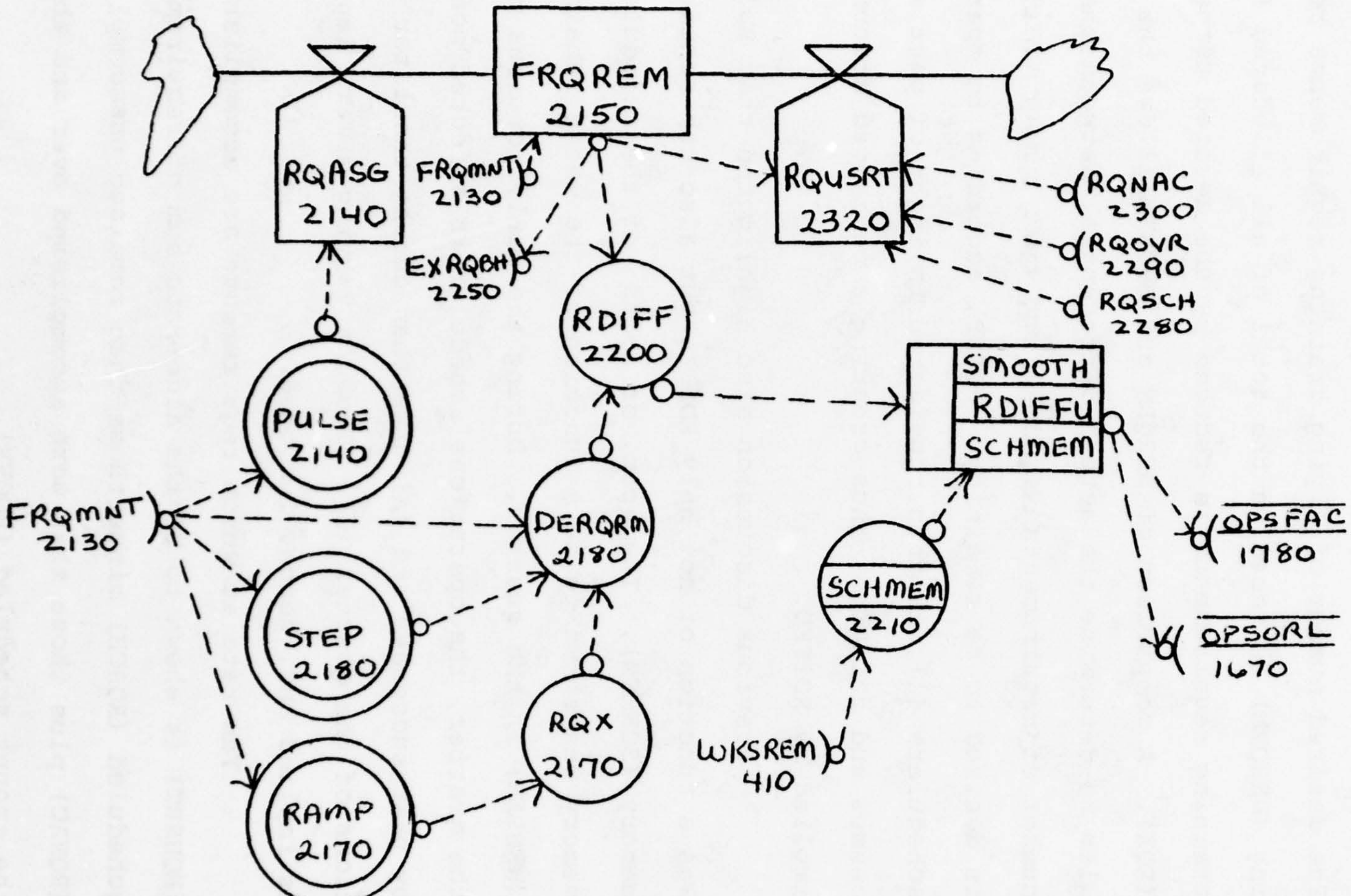

Fig. 44. Flying Training Requirements Sector--Flow Diagram 1

level of flying training requirements remaining (FRQREM) thus creating the impetus for scheduled wing activity. The desired number of flying training requirements remaining (DERQRM) is based on the total of all allocated flying training requirements as reduced by the desired usage rate (RQX). A comparison of DERQRM and FRQREM allows the scheduler to determine the actual differential between the actual number of requirements remaining and that number which is desired to be remaining. RDIFF, according to operations schedulers (1), is then considered in light of past successes and failures, thus creating a perceived status implied by RDIFFU.

Previous discussion also highlighted that RDIFFU was a function of not only RDIFF, but also the scheduler's memory (SCHMEM), The span, or focus, of the scheduler's memory was shown to be a function of the weeks remaining (WKSREM) in the quarter. During the early portions of the quarter, the operations scheduler is affected more by past successes and failures than during the later portions of the quarter (1). Thus, a varying memory length is implied and, hence, included.

The rate at which requirements are accomplished (RQUSRT) is shown to be the algebraic sum of requirements scheduled (RQSCH) minus those that remained unaccomplished (RQNAC) plus those that were accomplished over and above the amount scheduled (RQOVR).

The final subpart of the Flying Training Requirements Sector is presented in Figure 45. Two of the basic parameters from which system operation progresses are shown in Figure 45. BASRQS is that number of requirements which, as a minimum, should be accomplished in a six-hour sortie. In an earlier discussion, it was shown that a minimum of 5.6 requrements per flying hour should be accomplished given the following three factors: a 1400-hour flying allocation, 391 flying training requirements per crew (1), and twenty crews assigned. Thus, in a six-hour sortie (BDESHR), approximately thirty-three requirements should be accomplished, as indicated in Equation #2100.

The selection of the six-hour sortie length as the basis for future requirements calculations was based on two considerations. First, Loring AFB personnel indicate that, given the nature of the B-52 training mission, a six-hour sortie length is the minimum desirable (14). Second, by establishing this low base length, system operation would be allowed a wider range of flexibility in establishing the required sortie lengths. As will be shown in the next chapter, this will indeed be the case.

The number of requirements scheduled is shown to be a function of the variables OVRBAS and BASRQS. BASRQS has previously been discussed. OVRBAS (the percent increase in sortie length actually scheduled relative to BDESHR), however, remains to be discussed.

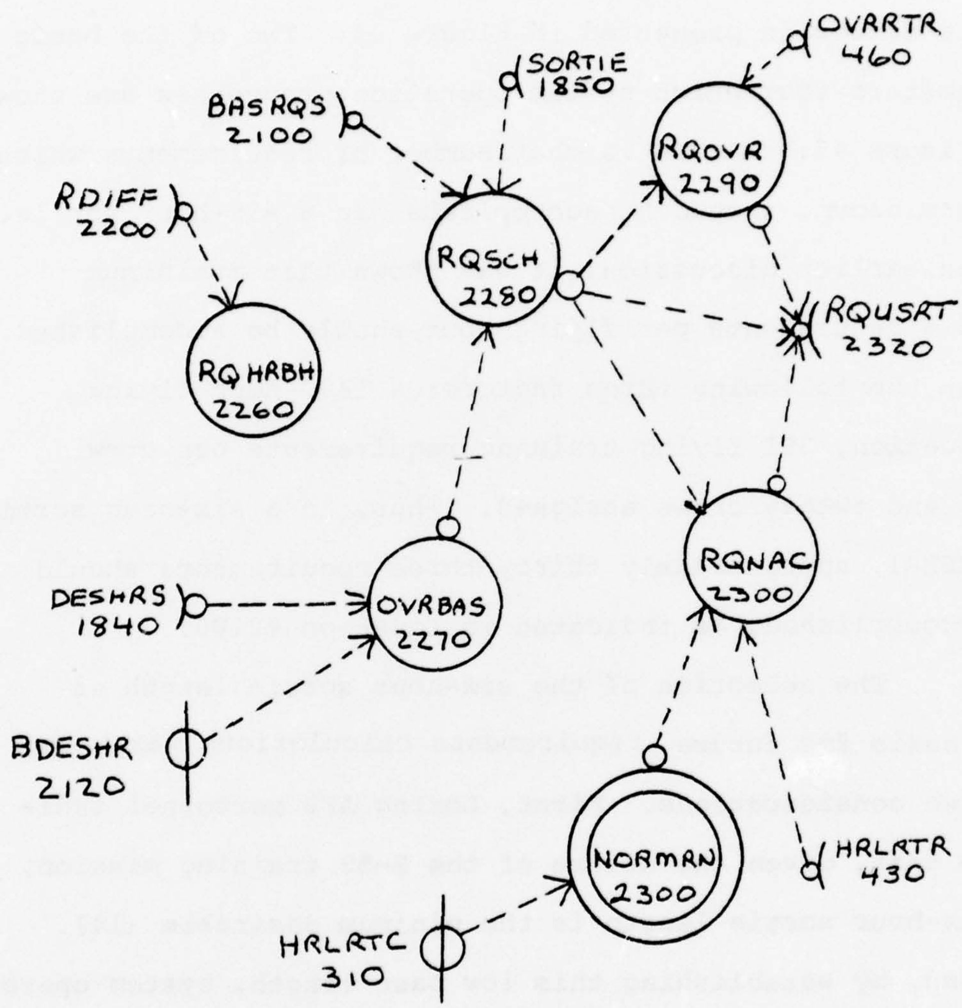

Fig. 45. Flying Training Requirements Sector--
Flow Diagram 2

OVRBAS implies the percentage increase in negotiated sortie length (DESHRS) over the six-hour base length (BDESHR). Thus, by multiplying the ratio of DESHRS to BDESHR times BASRQS, the scheduler can determine the appropriate number of requirements to be scheduled per sortie. A subsequent multiplication by the number of scheduled sorties will provide the total number of requirements to be scheduled during the upcoming week.

The number of requirements that are accomplished over and above the number scheduled (RQOVR) is determined by multiplying the overfly rate times the number of requirements scheduled, as shown in Equation #2290. Calculation of the number of requirements not accomplished (RQNAC), however, requires additional explanation.

Loring AFB schedulers (1) indicate a generally greater loss rate is associated with requirements than is realized with sorties and flying hours. For example, a sortie may take off on-time and yet find enroute weather intolerable. The pilot may then elect to return to base and accomplish pilot proficiency activity for the duration of the scheduled mission. While the pilots are accomplishing additional, unscheduled requirements, the total crew accomplishment rate is vastly reduced. Hence, while the mission was flown as planned, in terms of length, many of the scheduled requirements remained unaccomplished.

Thus, an increased loss rate for flying training requirements seems warranted.

In order to implement the required increased loss rate, a double randomizing technique was employed. The normal loss rate (HRLRTR) is calculated by randomizing, in a normal distribution, the scheduler's perceived loss rate (HRLRTC). Thus, to obtain an increased loss rate for requirements, HRLRTC was again randomized in a normal distribution, using a standard deviation of four times the previously utilized standard deviation, and the larger of the two randomizing actions was selected as the flying training requirements loss rate. Equation #2300 describes the calculation of the requirement loss rate.

The character of the distribution generated by Equation #2300 was investigated in the following manner. Ten thousand variates were generated from each of the above-mentioned loss rates, first with the original 0.03 standard deviation and then with the increased 0.12 standard deviation. The larger of the two generated values was selected and recorded as a separate data set. The mean and standard deviation of this data set was then determined. A histogram, with additional statistical information, of the resultant data set is presented in Figure 46. As indicated, the mean loss rate for flying training requirements is 16.83 percent. Thus, the resultant distribution generates approximately a 5 percent greater loss rate associated with flying

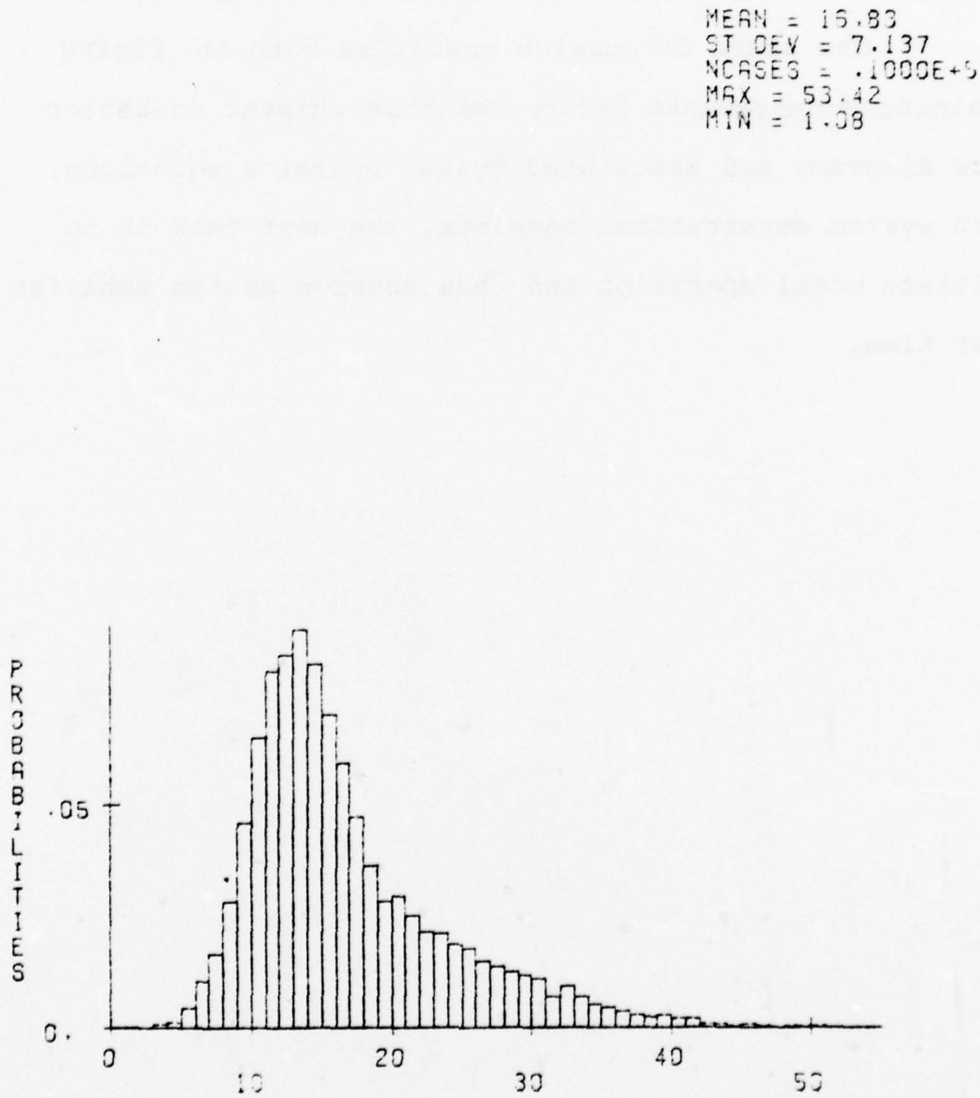

Fig. 46. Requirement Loss Distribution

training requirements than is applied to other variables such as sorties and flying hours. It was felt that 10,000 variates were sufficient to construct a reasonable representation of the requirements loss rate distribution (10).

The above discussion concludes both the Flying Training Requirements Sector and this chapter on sector flow diagrams and associated System Dynamics equations. With system construction complete, the next task is to initiate model operation and thus observe system behavior over time.

CHAPTER V

SYSTEM BEHAVIOR AND VALIDATION

Introduction

The purpose of this chapter is to present system behavior over time. Points to be noted while studying the behavior include policy implications and inherent interactions. One other noteworthy point should be amplified.

One should be alert to the possibilities of counter-intuitive behavior when observing a system through time. As Forrester noted, ". . . a complex information-feedback system designed by happenstance or in accordance with what may be intuitively obvious will usually be unstable or ineffective [5:15]." Hence, a complex system may produce other than expected results.

Once the time-generated behavior of the system has been presented and appropriate comments made, the issue of validity will be addressed. Basic system behavior, however, is the initial topic of discussion.

The Wing Level Scheduling Process

Time-generated behavior of the Wing Level Scheduling Process is presented in Appendix C. The appendix contains one-year plots of forty-one different variables which are

of primary interest in this system. Each page of Appendix C contains the plot of thirteen weeks' (or one quarter's) behavior. The four successive plots which make up the total years' behavior for the variable of interest are chronologically ordered. The variables being plotted are indicated at the top of the first plot of the year. The scaling along the left vertical axis indicates time and points are plotted every 0.25 weeks. As will be noted, most of the plots contain at least three, and sometimes four, variables. This technique of multiple variables per plot was used in the interest of efficiency and to enhance the reader's perception of causal relationships as they exist in the system. The total number of plots in Appendix C is fifty-two. Unhurried study of these plots, therefore, will provide a basis for greatest understanding.

The first four plots contain the variables HRLRTR (the loss rate realized by the wing), RDIFF (the difference between actual flying training requirements behind and desired requirements behind), and RDIFFU (the scheduler's perceived requirement differential based on his memory). The primary purpose of this plot is to emphasize the uncertainty associated with HRLRTR and show its effects on RDIFF and RDIFFU.

The second series of plots contains the variables ACTMHR (actual hours flown per aircraft per week), HRAVFL (the total number of hours that maintenance will provide

from its available aircraft), and HRSACT (the total number of hours that will be scheduled for the upcoming week). As indicated, HRSACT and HRAVLF are always equal in the system when no external problems are introduced. This behavior supports the earlier mentioned policy that maintenance will provide all requested flying hours up to the physical limit of forty-five hours per aircraft per week. While ACTMHR does vary somewhat, it follows the general trend established by HRSACT as would be expected.

The third series of plots contain the variables DESHRS (the negotiated sortie length), SORTIE (the negotiated number of sorties to be scheduled), OPFACR (the bargaining power or pressure realized by the operations scheduler), and MXFACT (the bargaining power or pressure realized by the maintenance scheduler). Two points are to be noted in these plots. First, OPFACR and MXFACR are inverse images of each other. This is to be expected since the total of both pressures must equal one. Also, SORTIE and DESHRS vary inversely. This also is to be expected for a given number of hours scheduled.

The fourth series of plots contain the variables ACAVAL (the total number of available aircraft), INMX (the number of aircraft involved in major maintenance), and ACON (the number of aircraft on alert). As will be seen with COAL (the number of crews on alert), ACON always

equals four which is the alert requirement. It can also be seen that ACAVAL and INMX vary inversely.

The fifth series of plots contain the variables ACAVLF (aircraft available to fly), ACSCHF (aircraft scheduled to fly), and FLYAC (the number of aircraft involved in flying activities at any given moment). It is seen that ACAVLF and ACSCHF are always equal. This is expected since the policy previously discussed dictates that all available aircraft will fly (DESORT equals 1). This philosophy is consistent with the judgements of maintenance personnel (11).

The sixth series of plots contain the variables FHRRMN (the actual number of flying hours remaining) and DEHRMN (the desired number of flying hours remaining). The executive level policy of an even spreading of hours over all the weeks of the quarter is highlighted by the smooth decrease of each variable.

The seventh series of plots contains the variables OPSORL (the operations desired sortie length), MXSORL (the maintenance desired sortie length), and DESHRS (the negotiated sortie length). DESHRS always must be resolved in the range between the two desires. This is evident. It is also possible to note, by referencing earlier plots, the various influences of pressure on DESHRS.

The eighth series of plots contain the variables OPSORT (the operations desired number of sorties), MXSORT

(the maintenance desired number of sorties), and SORTIE (the negotiated number of sorties that are to be scheduled). A direct analogy between these plots and the previous ones exist due to the interrelationship of sorties and sortie length. Sorties and sortie length vary inversely.

The ninth series of plots contain the variables OPFACR (the net bargaining power, or pressure, realized by the operations scheduler), MXFACR (the net bargaining power, or pressure, realized by the maintenance scheduler), and UREQOP (the utilization of maintenance personnel required to fulfill the operations sortie request). As seen, UREQOP varies directly with the number of sorties requested by the operations scheduler. As discussed in the previous chapter, the amount of pressure exerted on a maintenance organization is thought to be a function of the number of sorties that must be produced and, hence, the required utilization of maintenance personnel needed to produce the required sorties.

The tenth series of plots contain the variables SCHSPA (the scheduled number of sorties per aircraft per week), ACTMHR (the actual number of hours to be flown per aircraft per week), and BRKRTE (the overall failure rate realized by the wing). An initial point to note is that BRKRTE is higher, on the average, during the winter quarters than during the summer quarters. This seasonal variation in BRKRTE should be expected in that, during

the winter quarters, the operations scheduler will perceive a higher loss rate and, thus schedule more hours to be flown (HRSACT). As was explained in Chapter IV, one of the influencing factors in the determination of BRKRTE is HRSACT. The relationship of BRKRTE to both the number of sorties (ACTSPA) and the number of hours flown per aircraft (ACTMHR) can also be observed. As will be shown in the next chapter, BRKRTE is found to be, perhaps, the single-most sensitive variable in this system. An intuitive consequence of the sensitivity exhibited by BRKRTE can be presented at this time.

The sensitive nature of BRKRTE can precipitate continued instability in wing behavior even when superficial observations would indicate a condition of normal, stable operation should exist. For example, a wing may encounter a very large number of major maintenance problems during a given week. Thus, a requirements and flying hour backlog will be created. Once the malfunctions are repaired, the operations scheduler may desire to recoup all past losses in one week and, therefore, get back on schedule. Such action, however, can only result in a renewed increase in overall aircraft failure rate. Thus, large increases in aircraft utilization, as spawned by desires to catch up, will result in additional losses.

A large increase in HRSACT for the upcoming period will likely indicate that not only more sorties per aircraft,

but also more hours per aircraft will result. As previously indicated, the above three variables, HRSACT, ACTSPA, and ACTMHR are thought to be the primary determinants of a wing's overall failure rate (11). Thus, as the scheduler attempts to make up all past losses, BRKRTE is driven up even further. As BRKRTE increases to an even higher level, the number of aircraft available for flight (ACAVLF) will decrease. The scheduler may then attempt to gain an even greater amount of utilization from each remaining aircraft. Thus, the causal relationship is developed. An increase in BRKRTE will result in a decrease in ACAVLF which, for a given level of effort, will precipitate an even higher BRKRTE and so forth. Hence, a knowledge of the relationship of BRKRTE to its three primarily determinants seems warranted. Without this knowledge, schedulers, both maintenance and operations, may well be attempting to control a system which is not fully understood. Lack of understanding certainly does not enhance control. Further discussion of this matter will be presented in the ensuing chapter.

The eleventh series of plots contain the variables FRQREM (the actual number of flying training requirements remaining), DERQRM (the desired level of flying training requirements remaining), and RQSCH (the number of requirements scheduled).

As was seen in the flying hour sector, a level of desired requirements remaining (DERQRM) exists for all points in the quarters. If the actual number of requirements remaining (FRQREM) exceeds the desired number remaining, then pressure is created for the operations scheduler to make the necessary decisions to regain desired levels. The behavior of this decision process can be seen. The exhibited goal of this decision structure is to accomplish all assigned flying training requirements. It must be remembered, however, that the overriding executive level policy to spread all assigned flying hours evenly over the weeks of the quarter remains as the dominant factor. Thus, requirement accomplishment rates will be sacrificed, to a point, to insure a smooth flow of flying hours to both crews and maintenance.

The twelfth series of plots contain the variables RDIFFU (the perceived requirement differential as contained in the operations schedulers' memory), RDIFF (the actual requirement differential that exists), OVRBAS (the percentage increase in the negotiated sortie length relative to a six-hour base sortie length), and EXRQBH (the number of flying training requirements behind over and above four days of requirements).

A primary point to note is the relationship of RDIFFU to RDIFF. As shown, there is a substantial difference between RDIFF and RDIFFU in the earlier portions

of the quarter. As the quarter progresses, however, the scheduler's focus of attention becomes more directed to the actual RDIFF. In the last weeks of the quarter, a virtual one-to-one mapping of RDIFF and RDIFFU exists.

One other observation can be made concerning the twelfth plot. It is shown that OVRBAS varies correspondingly with RDIFFU. Recalling that the total number of hours actually scheduled (HRSACT) remains relatively stable, it is then possible to reconfirm the causal relationships involved. As RDIFFU increases, so does the desired sortie length requested by operations. Concurrent with an increase in RDIFFU is a similar increase in the bargaining power, or pressure, realized by the operations scheduler. Thus, increased sortie lengths (DESHRS) may result. If DESHRS increases, then the increase in OVRBAS is direct.

The final series of plots contain the variables OPCAVL (operations crews available), COAL (crews on alert), OPAVLF (operations crews available to fly), and FLYCRS (the number of crews involved in flying activities at any given time). This series of plots is presented primarily to display the relationships involved and to present a visual display of crew flows.

The systemic behavior of the Wing-Level Scheduling Process has been presented and discussed. It is now necessary to address the topic of validity.

System Validity

> The importance of justifying model detail rests on a fundamental working assumption, the assumption that if all the necessary components are adequately described and properly interrelated, the model system cannot do other than behave as it should. The converse is not true. . . [5:117].

Forrester's comments highlight an underlying purpose of Chapter IV. A fundamental prerequisite to system validation is a generalized agreement that all necessary components and proper interrelationships have been included. Thus, the detailed developments presented in Chapter IV were provided to facilitate this necessary agreement.

Forrester further relates that System Dynamics models are based on information and decision processes used by the practicing manager in the management of the organization (5:117).

> The power of industrial dynamics models does not come from access to better information than the manager has. Their power lies in their ability to use more of the same information and to portray more usefully its implications [5:117].

Thus, Forrester concluded that

> Validity of a model as a description of a specific system should be examined relative to (a) system boundaries, (b) interacting variables, (c) values of parameters [addition of a, b, and c mine].

Forrester indicated that the first and most important question to be addressed about model design concerns the correct selection of system boundaries (5:117). The system boundaries established for this research effort have been inherently identified in Chapter IV.

While significant environmental influences are taken into account, the structural boundaries presented encompass only the wing level processes. In light of the stated purpose of this research effort, it was felt that an extension of the present boundaries would only add to model size without enhancing task accomplishment. Similarly, a reduction in the established boundary structure would, it is believed, not permit an adequate inclusion of process detail. Thus, system boundaries were established as shown.

The second important question concerning model validity concerns a proper selection of interacting variables (5:118). Chapter III and Chapter IV presented an in-depth discussion of system conceptualization. The arguments presented in these chapters were primarily designed to convince a knowledgeable reader of the inherent logic of the system. All included policies and decision structures were based on an in-depth study of the actual system. Many interviews were conducted in order to maintain a continuing assurance that actual system structure was being replicated. If actual system structure has been replicated, then it is assumed that only proper and appropriate variables have been used. Thus, system validity is still upheld.

Forrester asserted that the third and least important question to be addressed when considering model validity is a concern for utilized parameter values.

Chapter IV presented a detailed explanation of many of the parameter values that were used. It can be seen, however, that while extensive efforts were made to use appropriate parameter values, the importance of absolute parameter value accuracy is minimal. Thus, system validity is still implied.

One final point concerning system validity remains to be addressed.

> A closed . . . industrial dynamics model should generate time patterns of behavior that do not differ in any significant way (judged within the framework of the objectives of the study) from the real system [5:119].

An initial step to compare model behavior with actual system behavior was taken.

Loring AFB personnel (1) provided the necessary information for all needed inputs to generate system behavior through time. The objective of this effort was to input actual parameter values to the conceptualized system and then compare generated system behavior with actual system behavior. The efforts were successful.

The information obtained from Loring AFB personnel (1) included the following:

1. Flying hour allocations for the first two quarters of 1978 (1358 and 1266 hours respectively).

2. An approximate number of useable operations crews (fifteen).

3. An approximate number of aircraft on station as opposed to assigned (fifteen).

4. The actual flying hour loss rates realized by the wing for each week of the first two quarters (listed in Table 1).

5. The actual number of hours scheduled and subsequently flown during each week (listed in Table 1).

6. The actual number of sorties scheduled for each week (listed in Table 1).

7. The average sortie length scheduled for each week of the first two quarters (listed in Table 1).

Several modificatons to system equations were necessary to input the Loring AFB data. It is to be noted, however, that no change or alteration was made to the conceptualized policy/decision structure. All generated behavior, therefore, was created by the same system structure implied in Appendix B. Appendix D presents the entire equation structure that was used to generate the test behavior. The modified equations, identified by line number, are listed in the opening lines of Appendix D.

The comparison of system behavior to actual behavior is presented in Table 1. The behavioral similarities are apparent. Relatively large differences, however, can be noted in weeks one, thirteen, and twenty-two. As shown in the week number column, the identified weeks

TABLE 1

LORING AFB SIMULATION RESULTS

(Test Behavior Versus Actual)*

Week No.	Actual Loss Rate	Hours Scheduled	Hours Flown	Sorties Scheduled	Avg. Sortie Length Scheduled
1 (Holiday)	.038	92.2/65.2	92.2/63	13/7	6.9/9.3
2	.418	129.1/135.0	76.3/78.6	14/15	9.4/9.0
3	.345	131.3/143.6	87.3/94.3	14/16	9.5/9.0
4	.111	131.145.6	117.0/129.5	14/16	9.4/9.1
5	.038	128.6/136.0	125.1/130.9	14/15	9.2/9.1
6	.174	126.4/136.0	105.2/112.3	14/15	9.1/9.1
7	.096	124.5/125.3	114.8/113.3	14/14	8.9/9.0
8	.080	121.6/118.0	112.8/108.6	14/14	8.6/8.4
9	.255	120.7/117.2	91.3/87.3	14/14	8.5/8.4
10	.015	118.7/125.7	117.8/123.8	14/14	8.5/9.7
11	.187	115.8/120.0	95.5/97.6	13/14	8.8/8.6
12	.334	121.4/105.4	81.3/70.2	13/13	9.5/8.1
13 (Buy None)	.000	121.8/148.6	123.1/148.6	12/14	10.0/10.6
14	-114	109.6/109.7	98.9/97.2	11/12	10.0/9.1
15	.125	108.6/139.7	95.2/122.3	11/15	10.0/9.3
16	.045	107.4/135.2	103.3/129.1	11/15	9.5/9.0
17	.037	105.8/136.1	103.2/131.0	12/15	9.1/9.1
18	.035	104.3/96.4	102.2/93.0	12/10	8.7/9.6
19	.198	104.0/98.9	84.8/79.3	13/11	8.3/9.0
20	.037	103.8/105.8	101.1/101.9	13/12	8.1/8.8
21	.109	103.2/107.7	92.3/96.0	13/12	7.9/9.0
22 (Holiday)	.129	103.7/75.7	92.1/65.9	13/9	7.9/8.4
23	.051	103.9/101.1	100.3/95.9	13/12	7.9/8.4
24	.030	102.9/100.0	101.7/97.0	13/12	8.1/8.3
25	.042	101.7/102.2	98.7/97.9	12/12	8.2/8.5
26	.000	98.6/59.5	99.7/59.5	12/7	8.5/8.5

*NOTE--Test behavior is listed first.

contained either a holiday or military exercise. Thus, the resemblance is even more pronounced. As was indicated, the above completes only a first step toward full system validation. This apparent success, however, should provide the impetus for further validation efforts.

Research objective number nine indicates that, following a study of model validity, an effort to study the effect of change on system behavior would be initiated. This is the subject of Chapter VI.

Chapter VI

EFFECTS OF CHANGE

Introduction

> When the manager had achieved a viable understanding and began to manipulate the model, he continuously gained new insights into his operation [13:12].

These words of McKenney as told by Shannon highlight the purpose of a chapter such as this. In this research, understanding increased with model development. System manipulation, however, provided even far greater insights. The purpose of this chapter is twofold. First, policy and parameter changes that were introduced into this system will be presented. Second, and more importantly, an attempt will be made to relate many of these newly found insights so that the reader, too, will understand.

Experiments

For an initial experiment in this research effort, a complete loss of all flying activities because of weather was introduced. This total loss of scheduled activity was initiated in the beginning of week 16 and concluded at the end of the same week. Plots of selected variable behavior, for the affected quarter, are presented in Figure 47. A discussion of the major insights gained as a result of this experiment is in order.

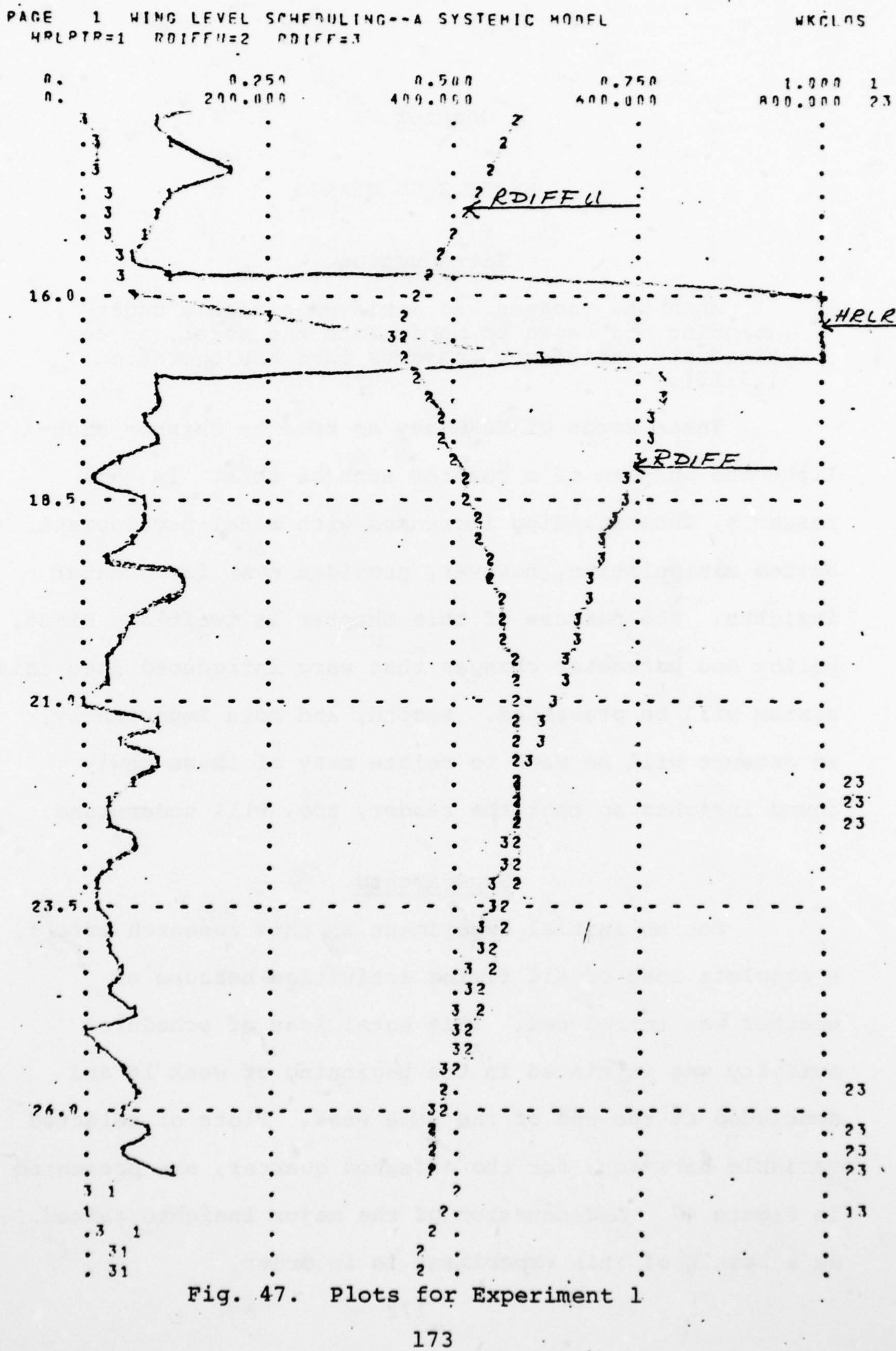

Fig. 47. Plots for Experiment 1

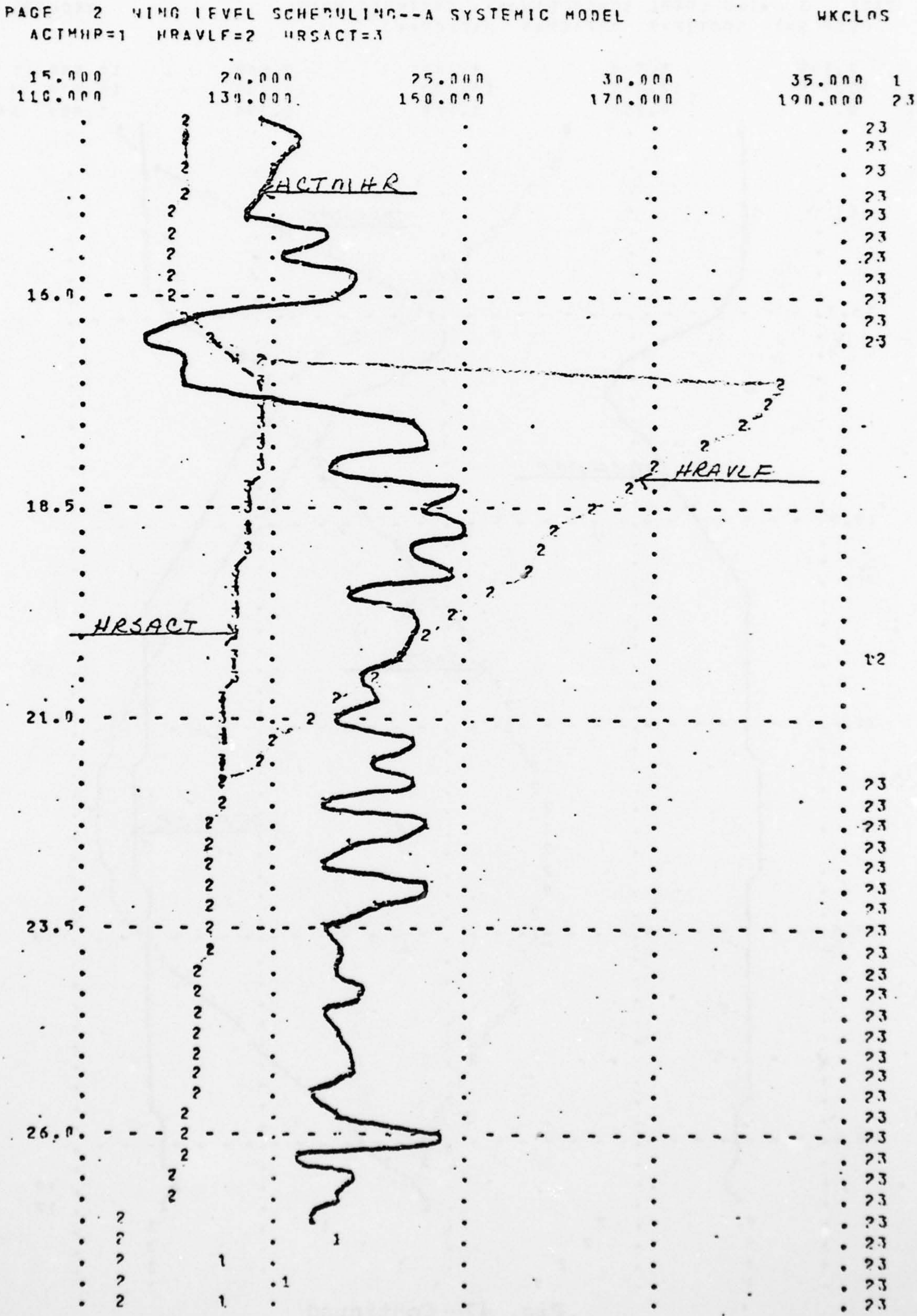

Fig. 47--Continued

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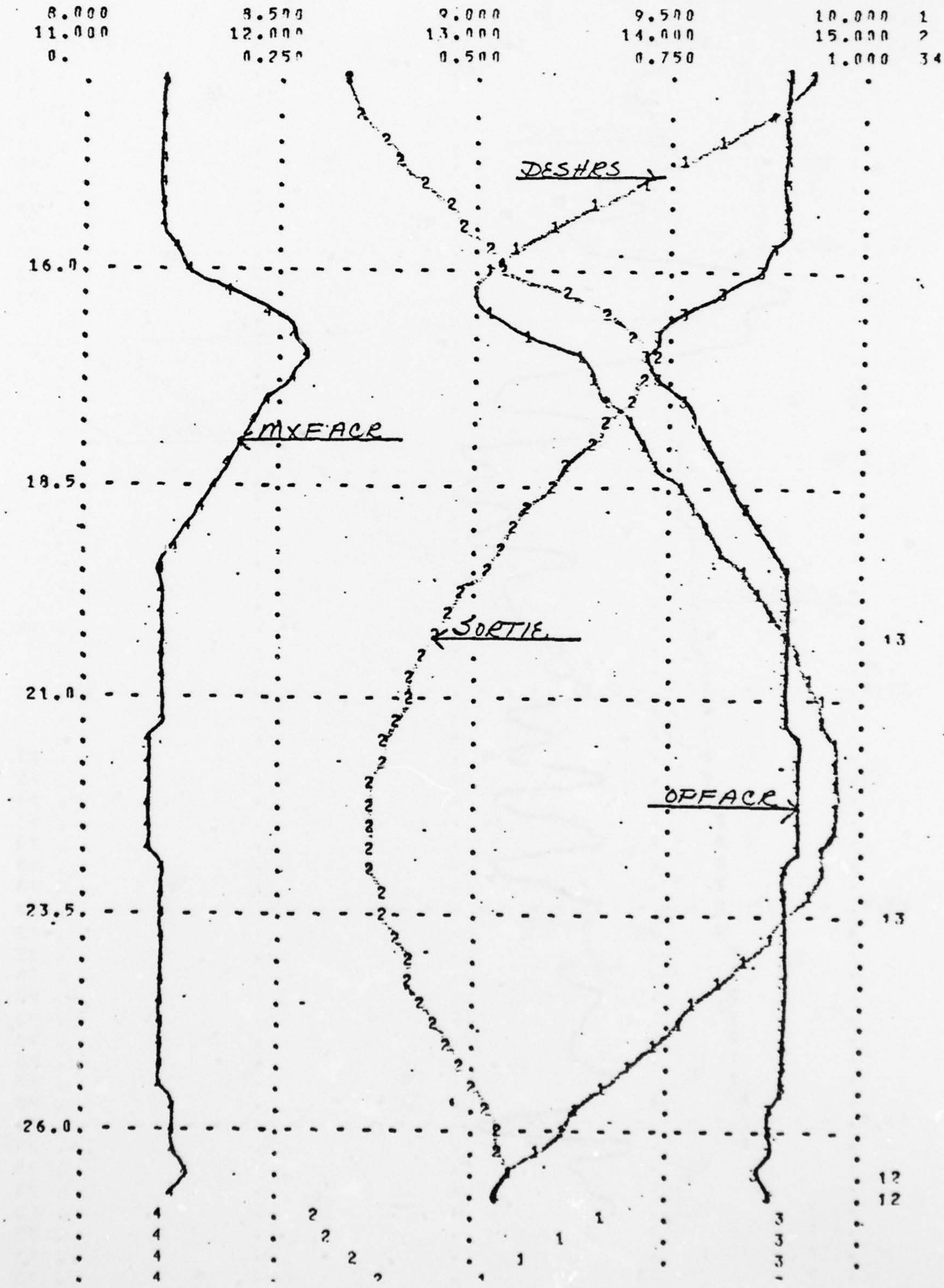

Fig. 47--Continued

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THE WING LEVEL SCHEDULING PROCESS. A SYSTEMS APPROACH.(U)
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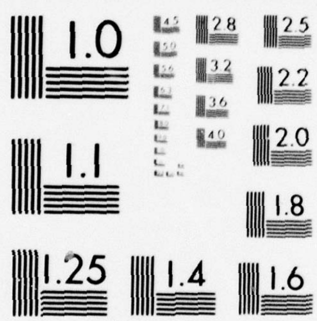

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

PAGE 4 WING LEVEL SCHEDULING--A SYSTEMIC MODEL WKCLOS
ACAVAL=1 INMX=2 ACON=3

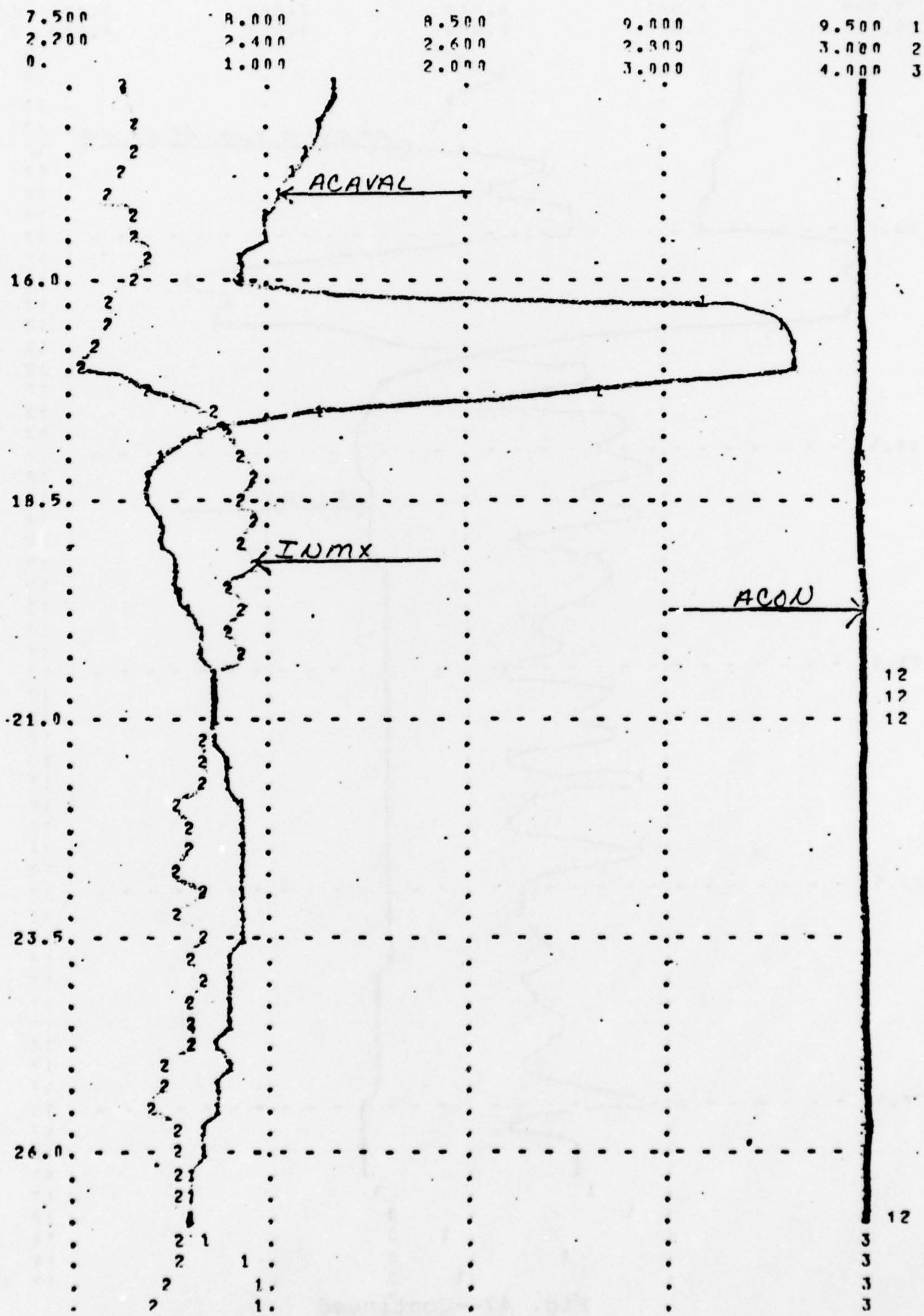

Fig. 47--Continued

PAGE 5 WING LEVEL SCHEDULING--A SYSTEMIC MODEL WKCLOS
ACAVLF=1 ACSCHF=2 FLYAC=3

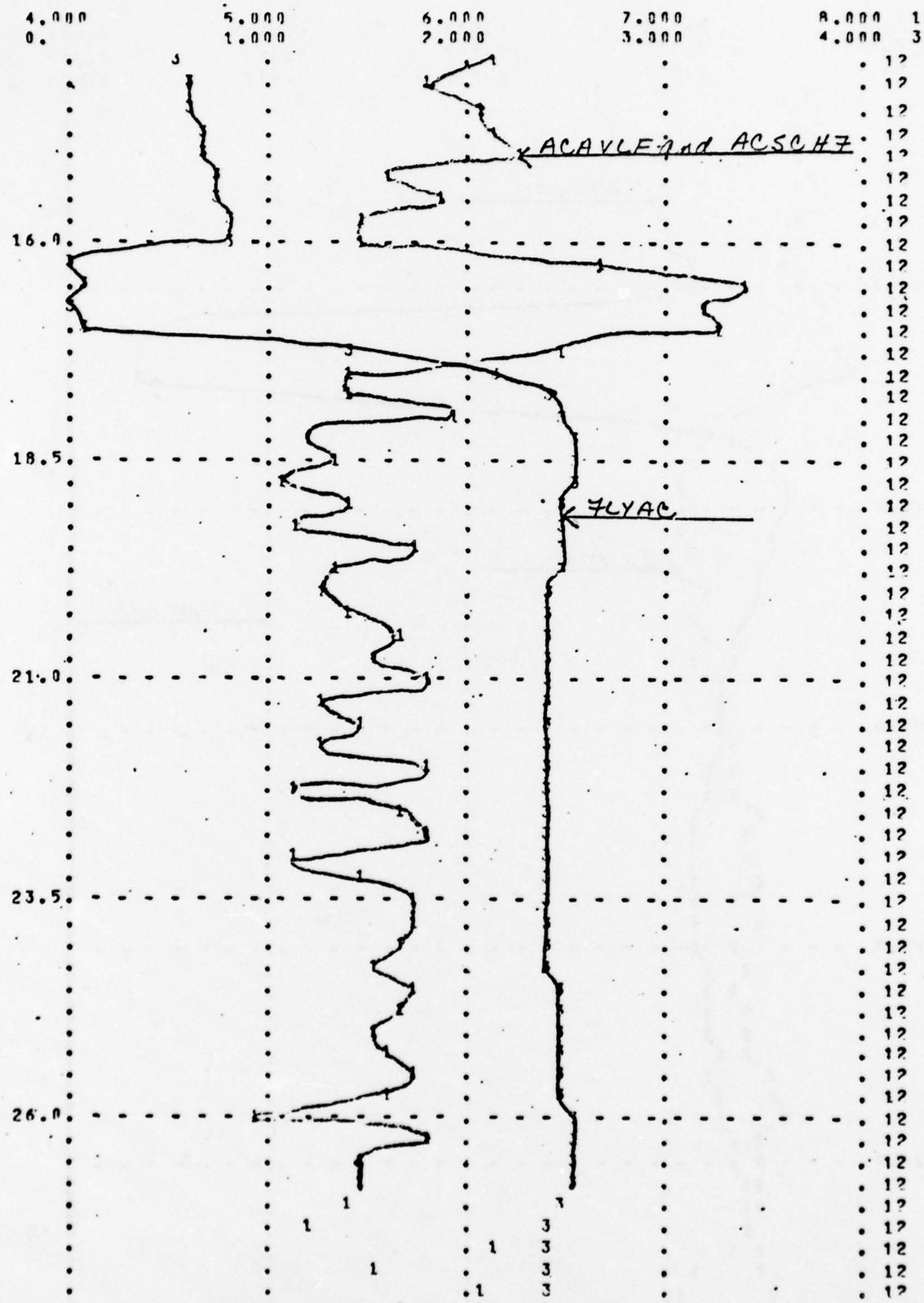

Fig. 47--Continued

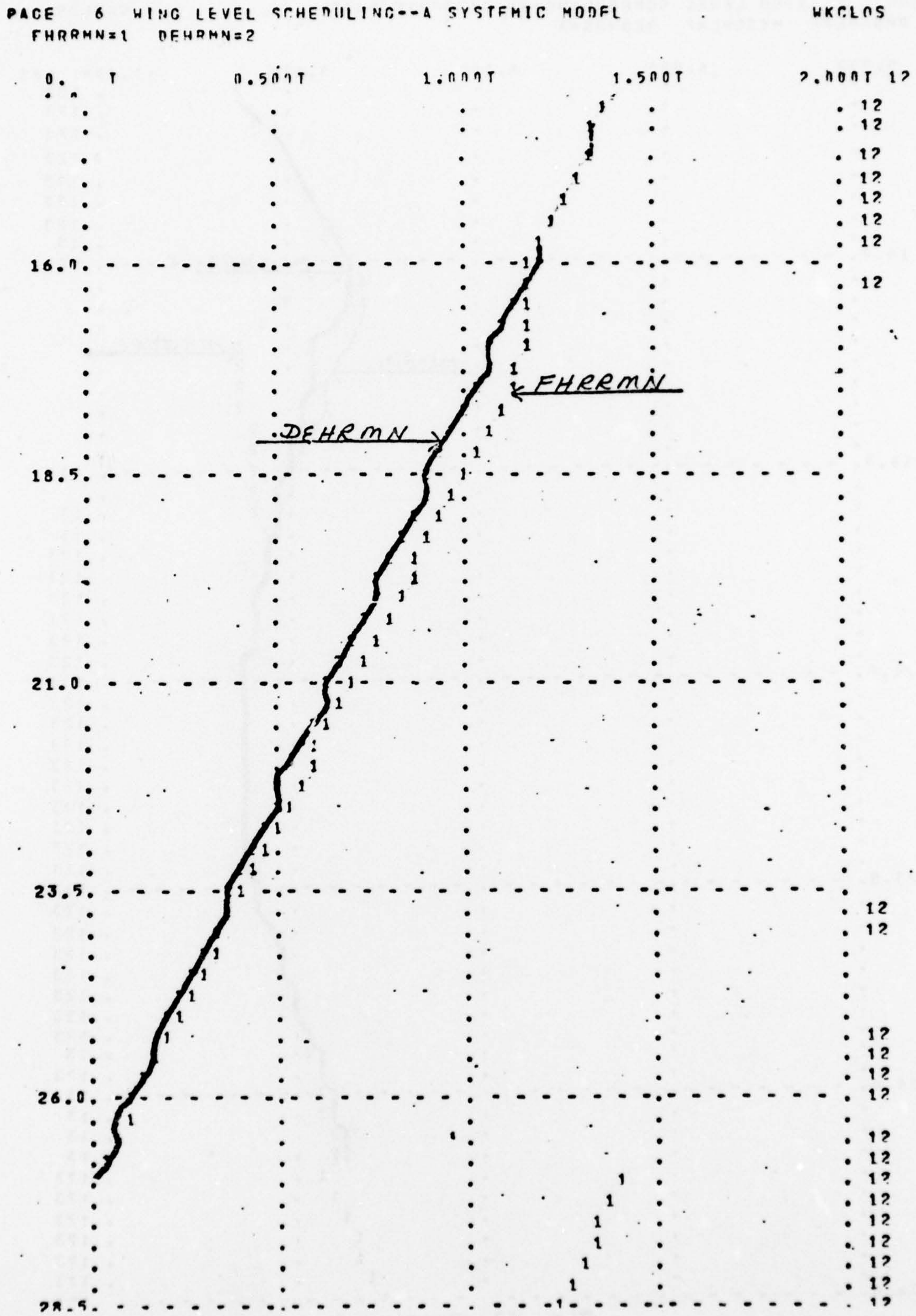

Fig. 47--Continued

PAGE 7 WING LEVEL SCHEDULING--A SYSTEMIC MODEL WKCLOS
OPSORL=1 MXSORL=2 DESHRS=3

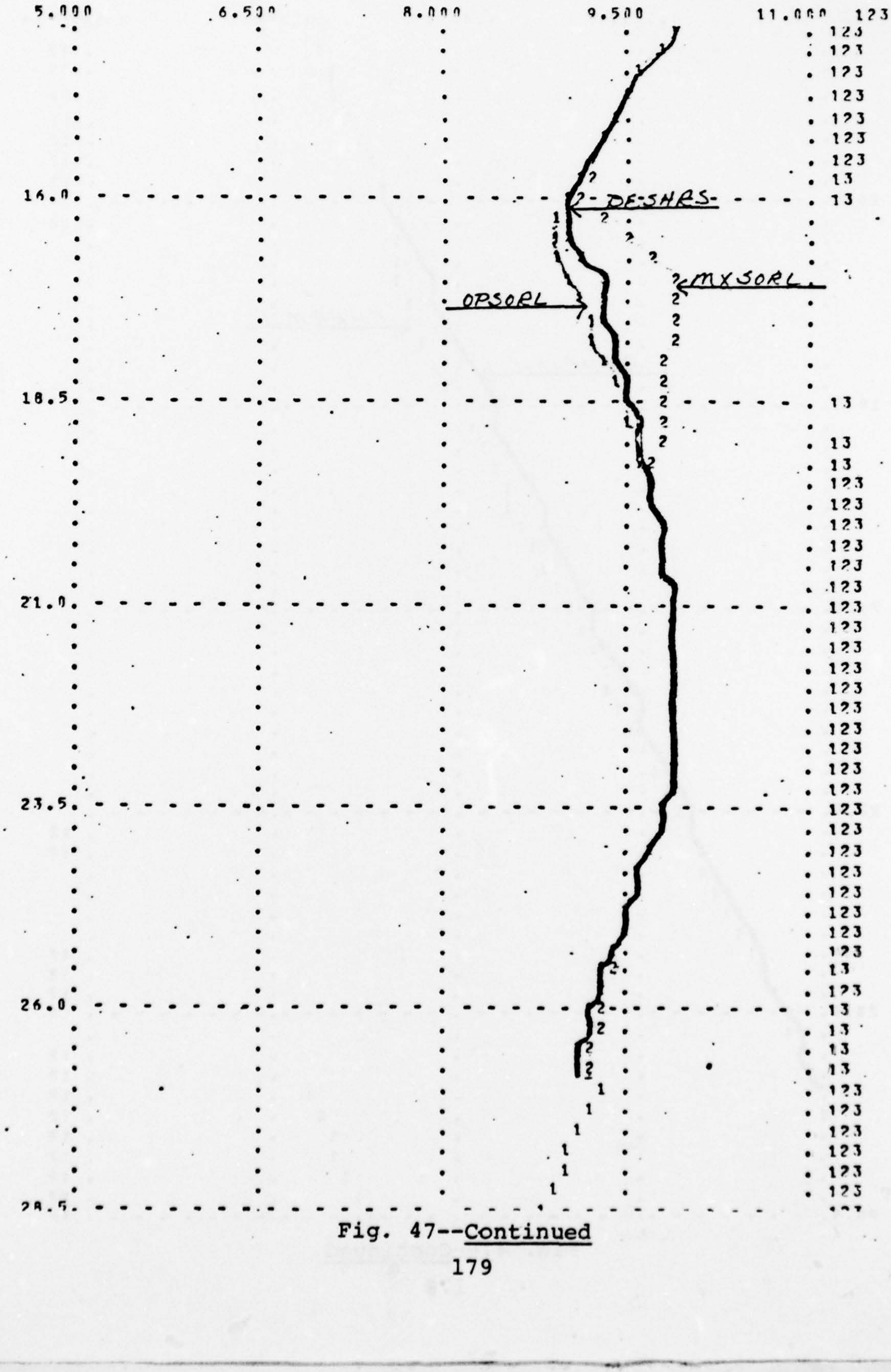

Fig. 47--Continued

PAGE 8 WING LEVEL SCHEDULING--A SYSTEMIC MODEL WKCLOS
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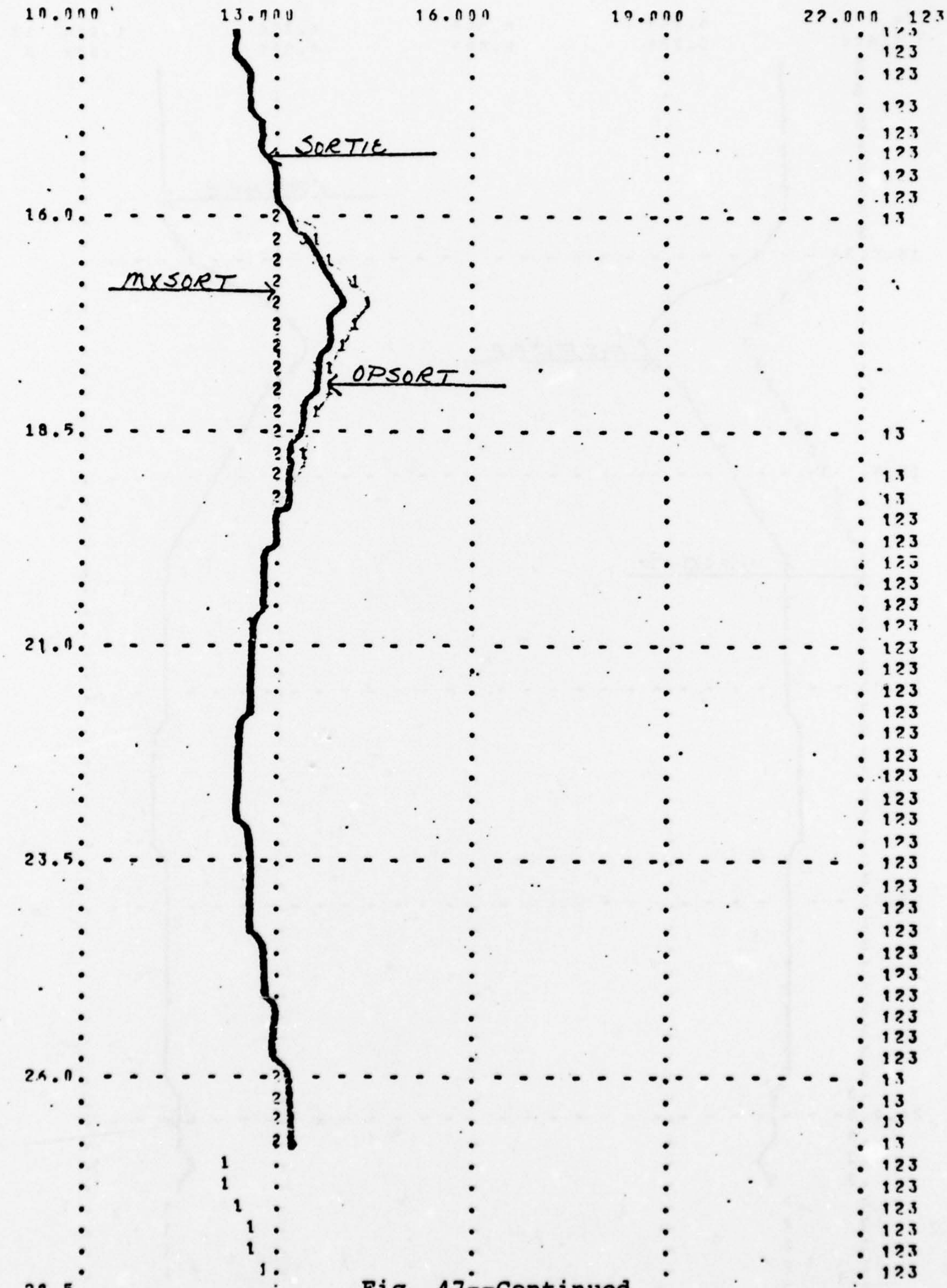

Fig. 47--Continued

PAGE 9 WING LEVEL SCHEDULING--A SYSTEMIC MODEL WKCLOS
OPFACR=1 MXFACR=2 UREQUP=3

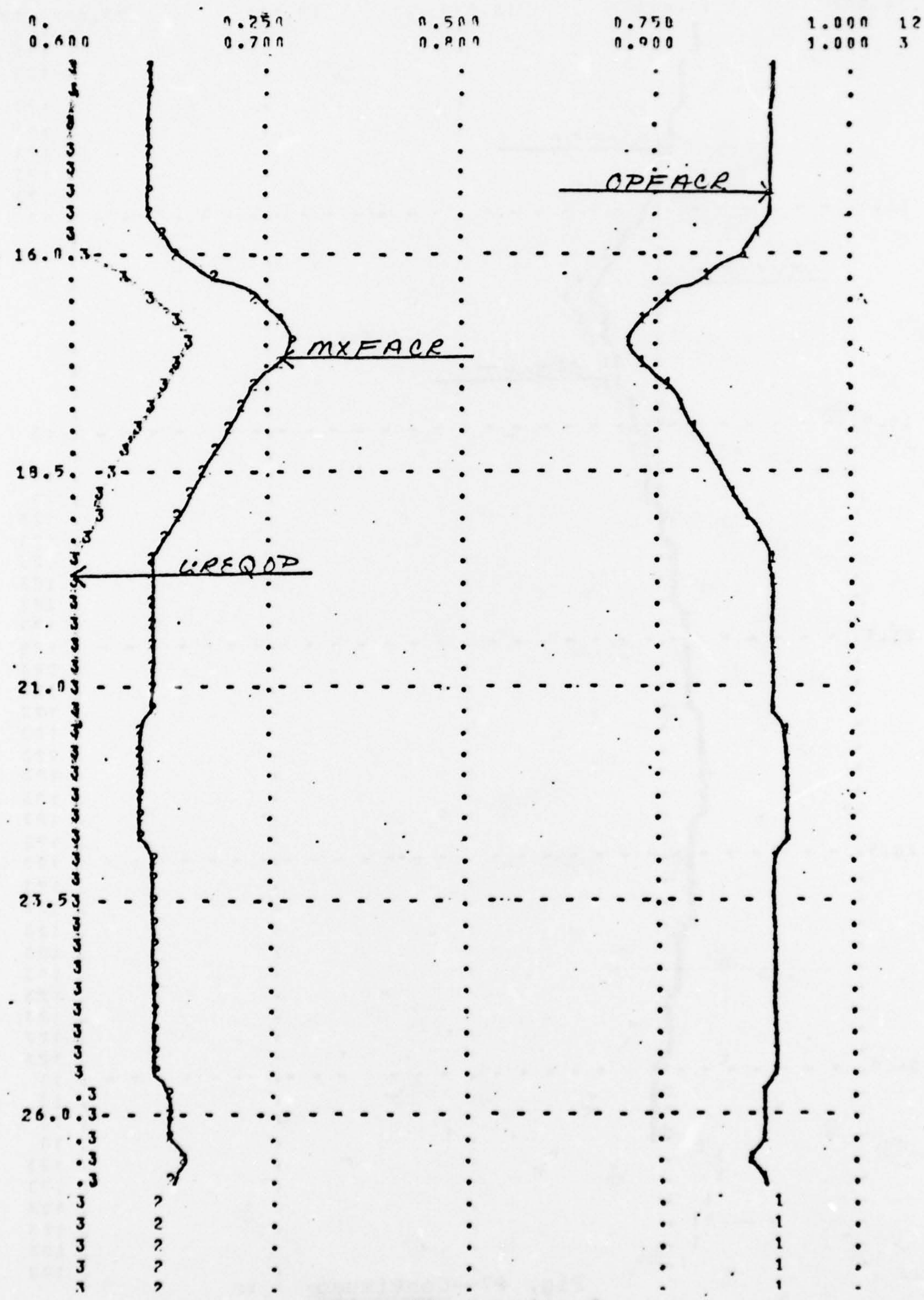

Fig. 47--Continued

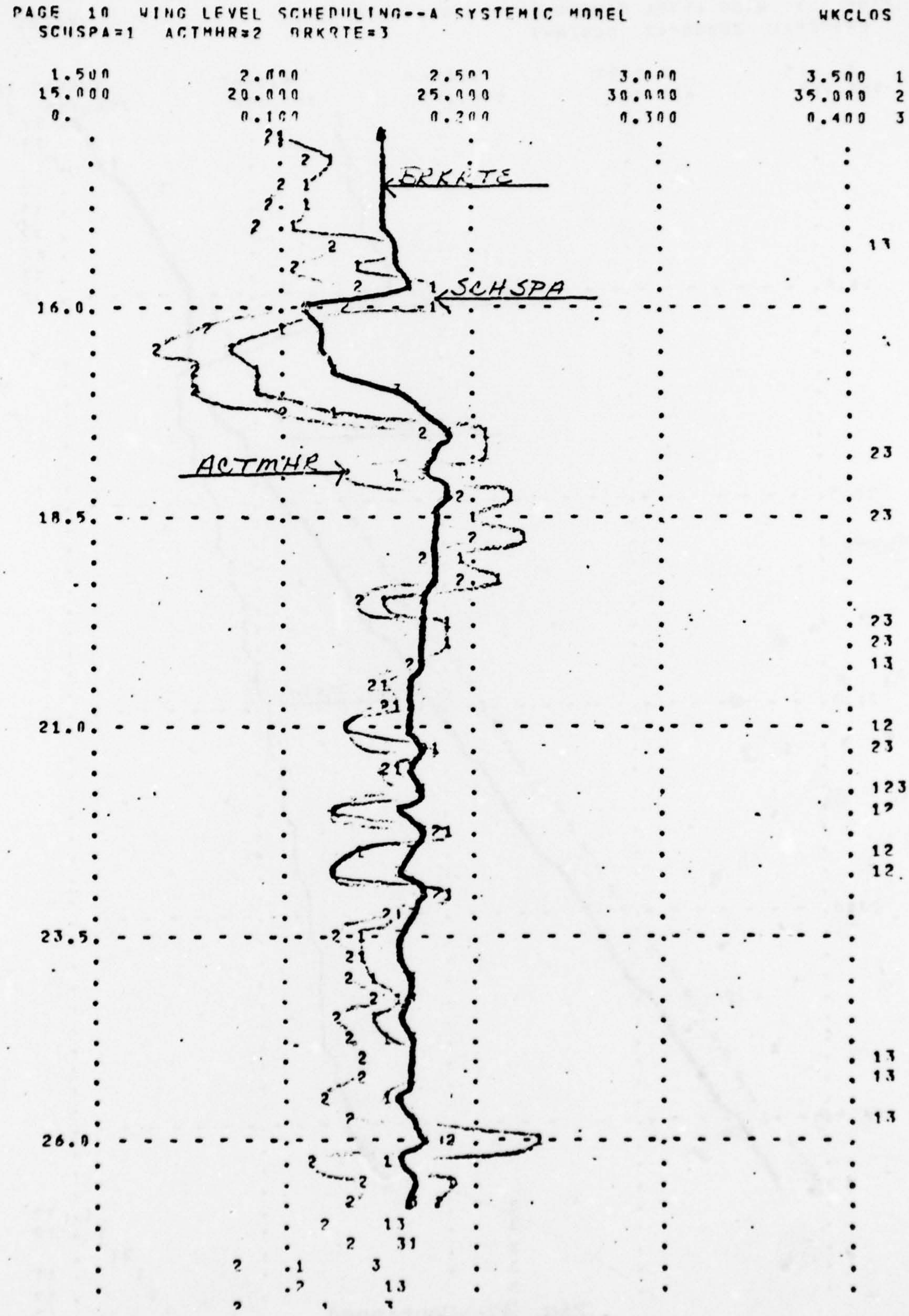

Fig. 47--Continued

PAGE 1 WING LEVEL SCHEDULING--A SYSTEMIC MODEL WKCLOS
FROREM=1 DERORM=2 RQSCH=3

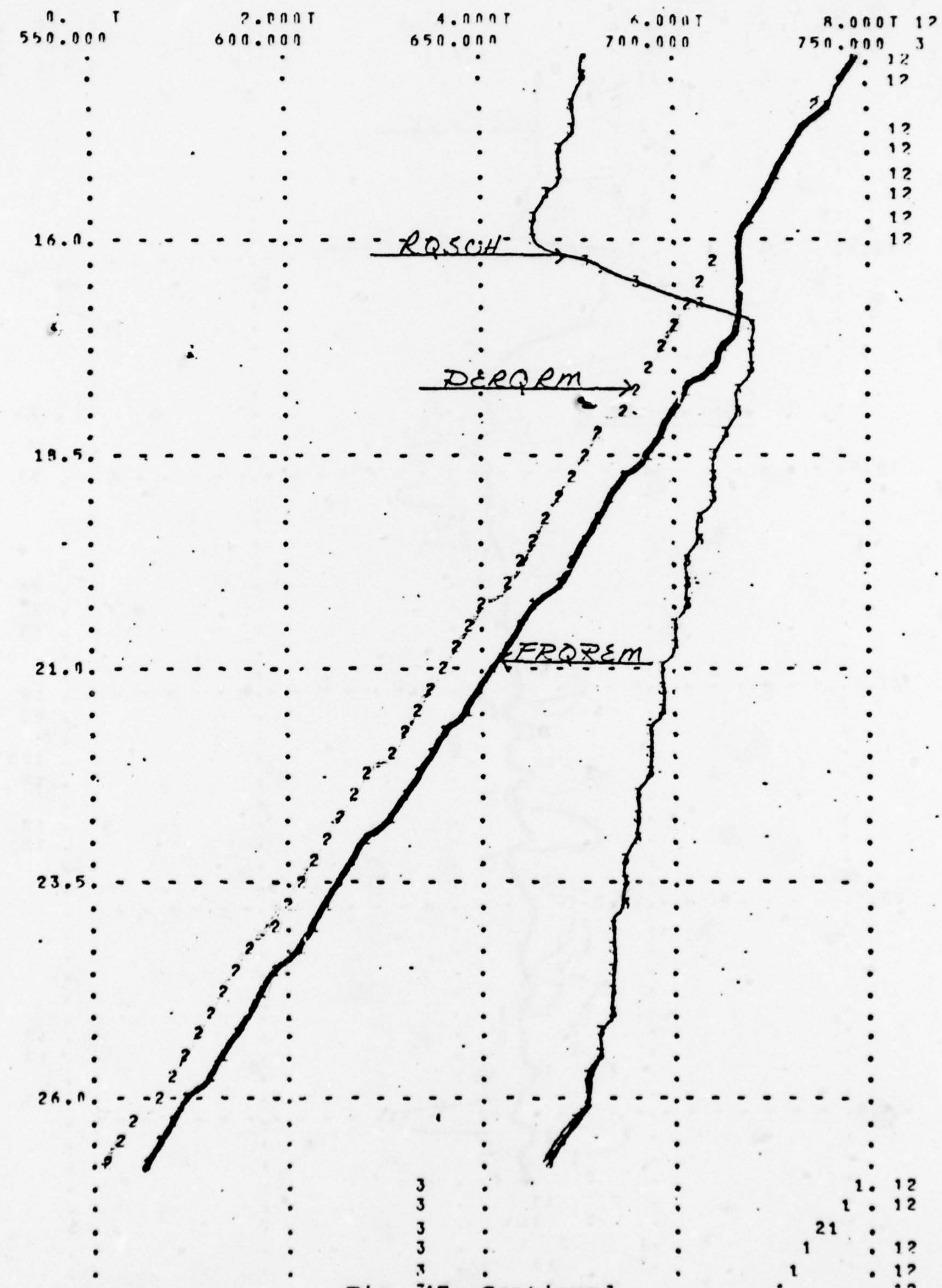

Fig. 47--Continued

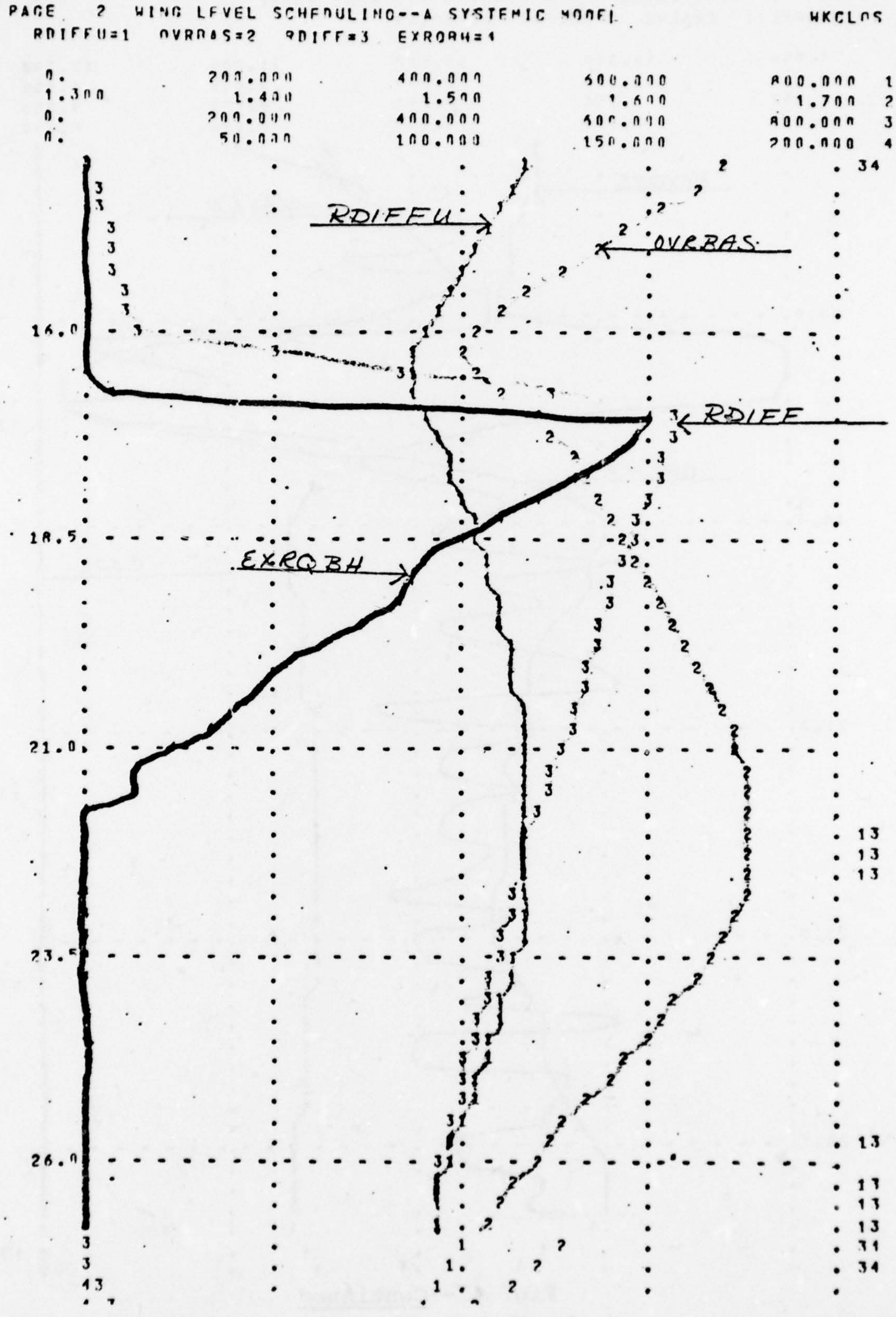

Fig. 47--Continued

PAGE 3 WING LEVEL SCHEDULING--A SYSTEMIC MODEL WKCLOS
OPCAVL=1 COAL=2 OPAVLF=3 FLYCRS=4

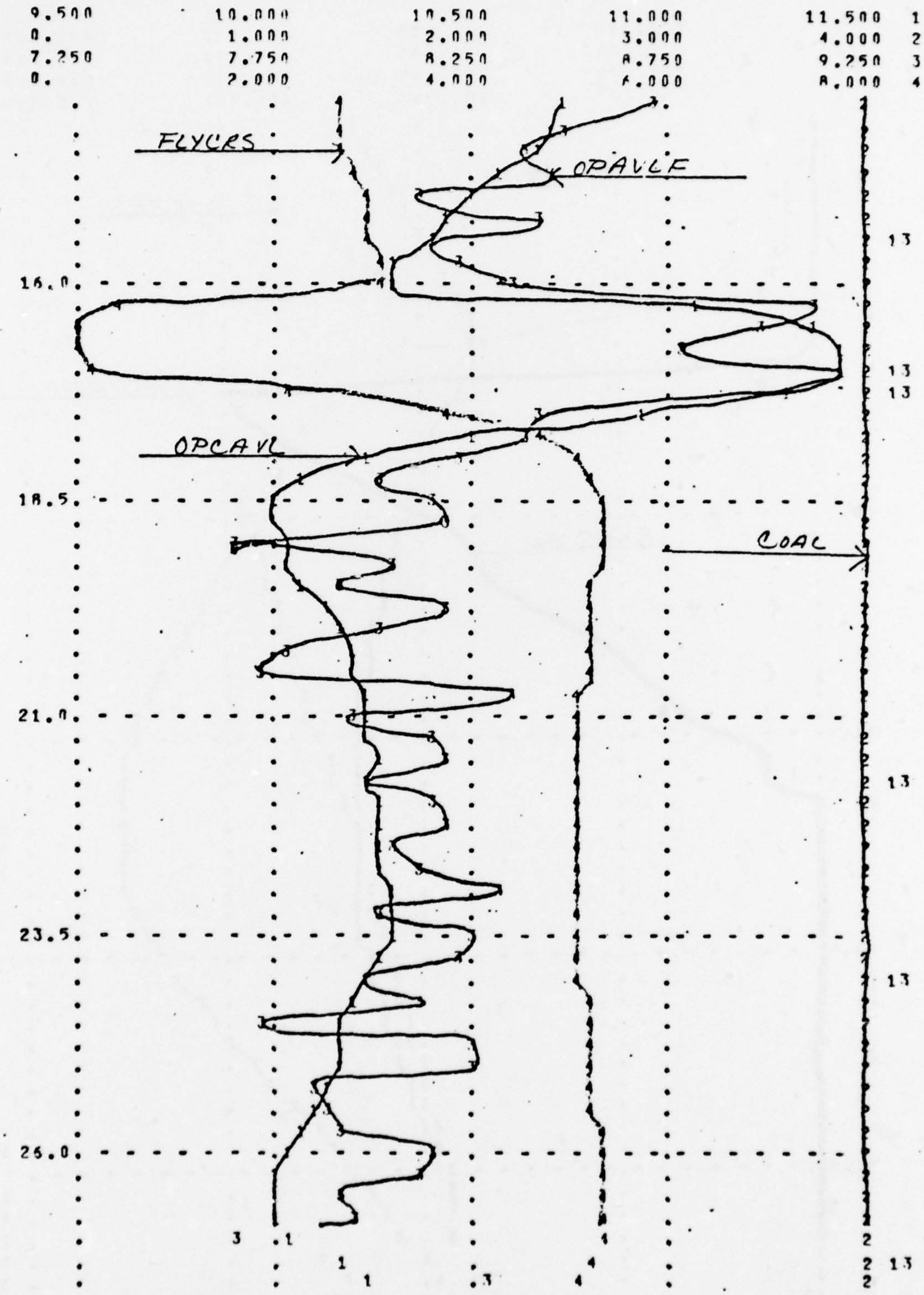

Fig. 47--Continued

As can be seen, RDIFFU (the perceived difference in flying requirements remaining versus desired remaining based on the scheduler's memory) increases at a relatively slow rate due to the scheduler's memory. Recalling previous discussions, it is realized that the slow increase in RDIFFU precipitates a gradual increase in demands placed on maintenance. The associated benefits of not subjecting maintenance to rapidly surging demands are acknowledged. The gradual increase in RDIFFU also spreads the increased efforts to recoup losses over a longer period. Thus, aircraft utilization increases at a gradual rate. It is therefore expected that the peak aircraft use rate associated with the catch-up period is less than that which would have been experienced with rapidly increasing use rates. The rationale for the above statement is that a small increase would, over the long term, allow a wing to recoup losses. The smaller increase in use-rate tends to effect a lower aircraft failure rate. Hence, it is expected that aircraft usage will peak at a lower overall rate than would be experienced otherwise.

The overall system behavior, however, was expected. This behavior is presented in the attached figure for reader edification.

The next experiment conducted with this system was to simulate a rapidly increasing requirement for maintenance in the wing's aircraft. A realistic scenario

analogous to this simulation could be a large increase in required maintenance due to extreme environmental factors such as those encountered in the northern tier states. System behavior for the affected quarter is presented in Figure 48.

Extreme behavioral fluctuations to the extent that both aircraft and crews are taken off alert is evidenced in the figure. BRKRTE (the overall aircraft failure rate realized by a wing) is shown to initially drop as the number of aircraft being flown rapidly decreases. It is also shown, however, that as the loss rates associated with flying training requirements and flying hours begin to increase, the scheduler attempts to fly the available aircraft for more and more hours. The result of this action is indicated by the large increase in BRKRTE. Although the increase in required maintenance is initiated in week 17 for a one-week duration, BRKRTE, ACAVLF, and other related variables require approximately four weeks to stabilize. Recalling that the scheduler's memory smooths otherwise rapidly surging demands on maintenance, the ramifications of responding only to current conditions with no memory of the past can be appreciated.

The third set of experimental conditions to which the system was subjected represented a combination of factors. In concert with the previously described increasing maintenance rate, a policy change was imposed on the

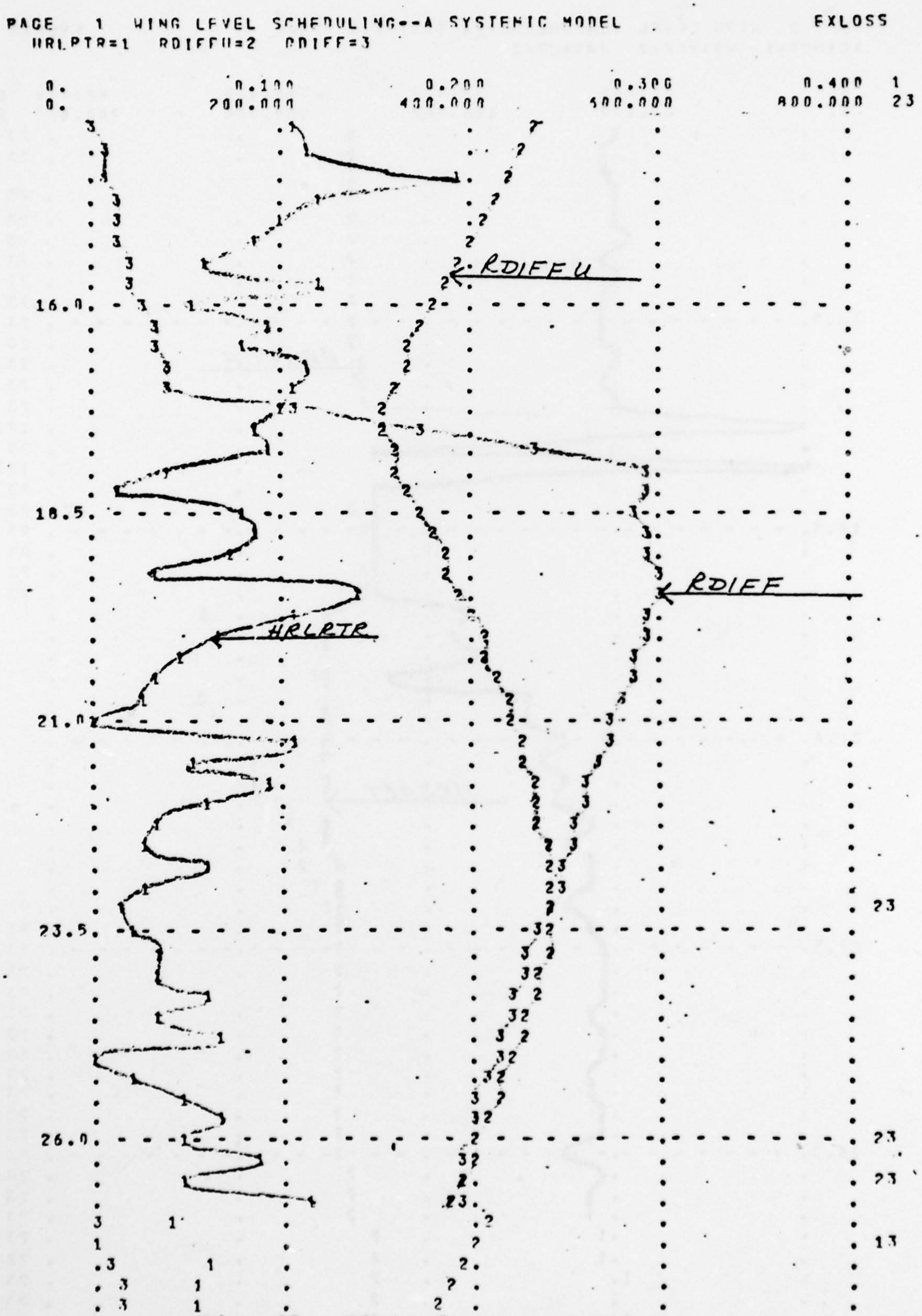

Fig. 48. Plots for Experiment 2

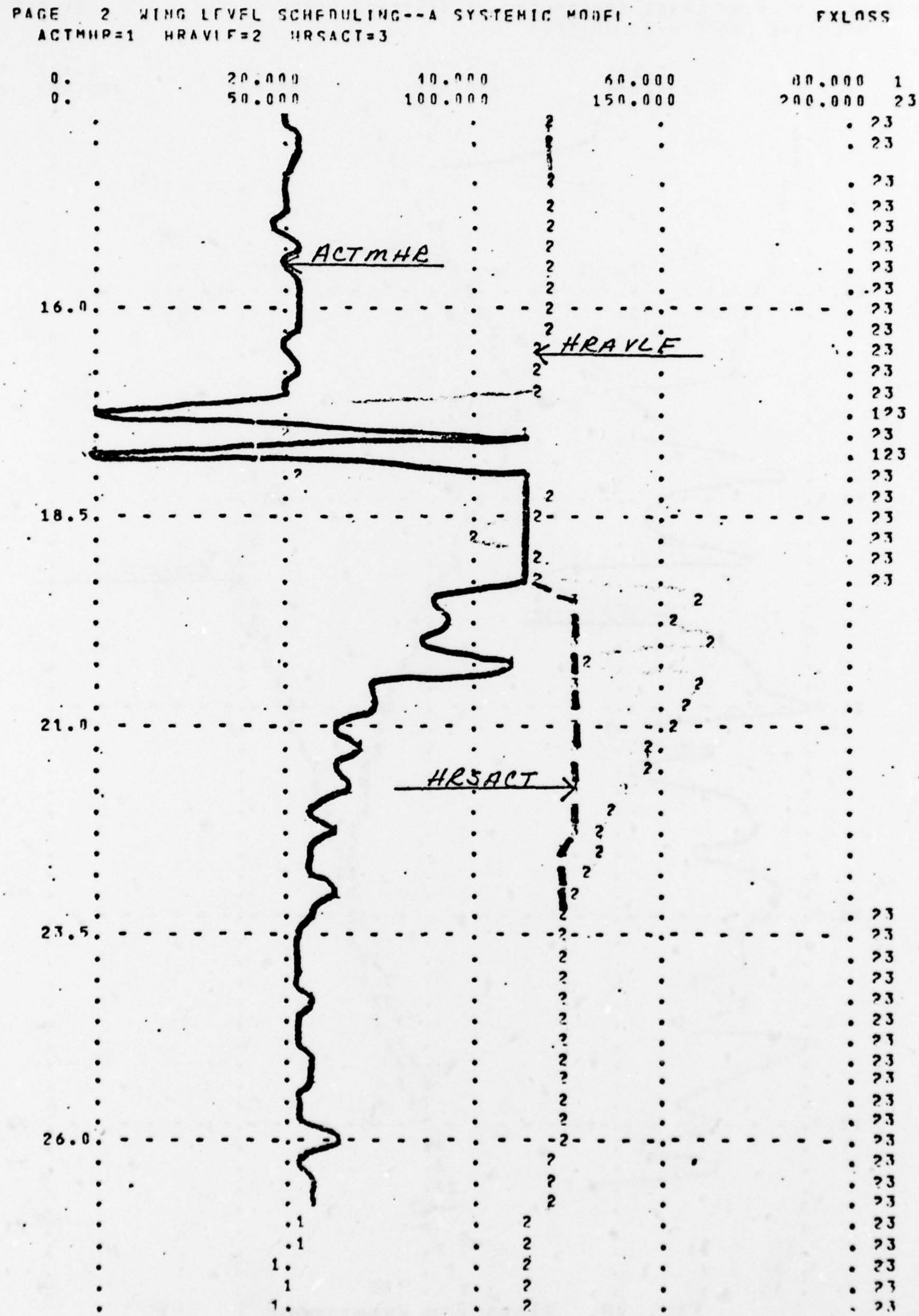

Fig. 48--Continued

PAGE 3 WING LEVEL SCHEDULING--A SYSTEMIC MODEL EXLOSS
DESHRS=1 SORTIE=2 OPFACR=3 MXFACR=4

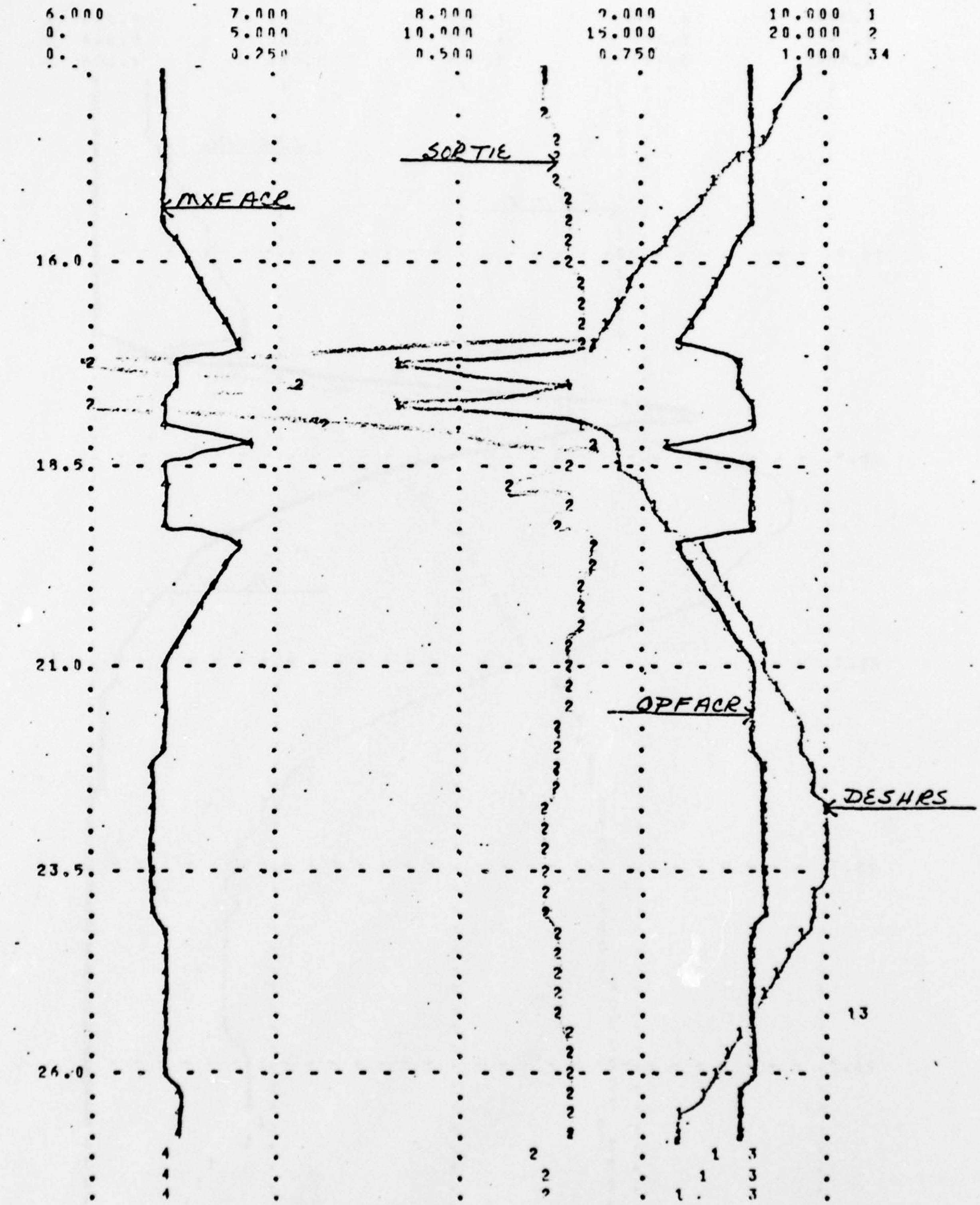

Fig. 48--Continued

PAGE 4 WING LEVEL SCHEDULING--A SYSTEMIC MODEL EXLOSS
ACAVAL=1 INMX=2 ACON=3

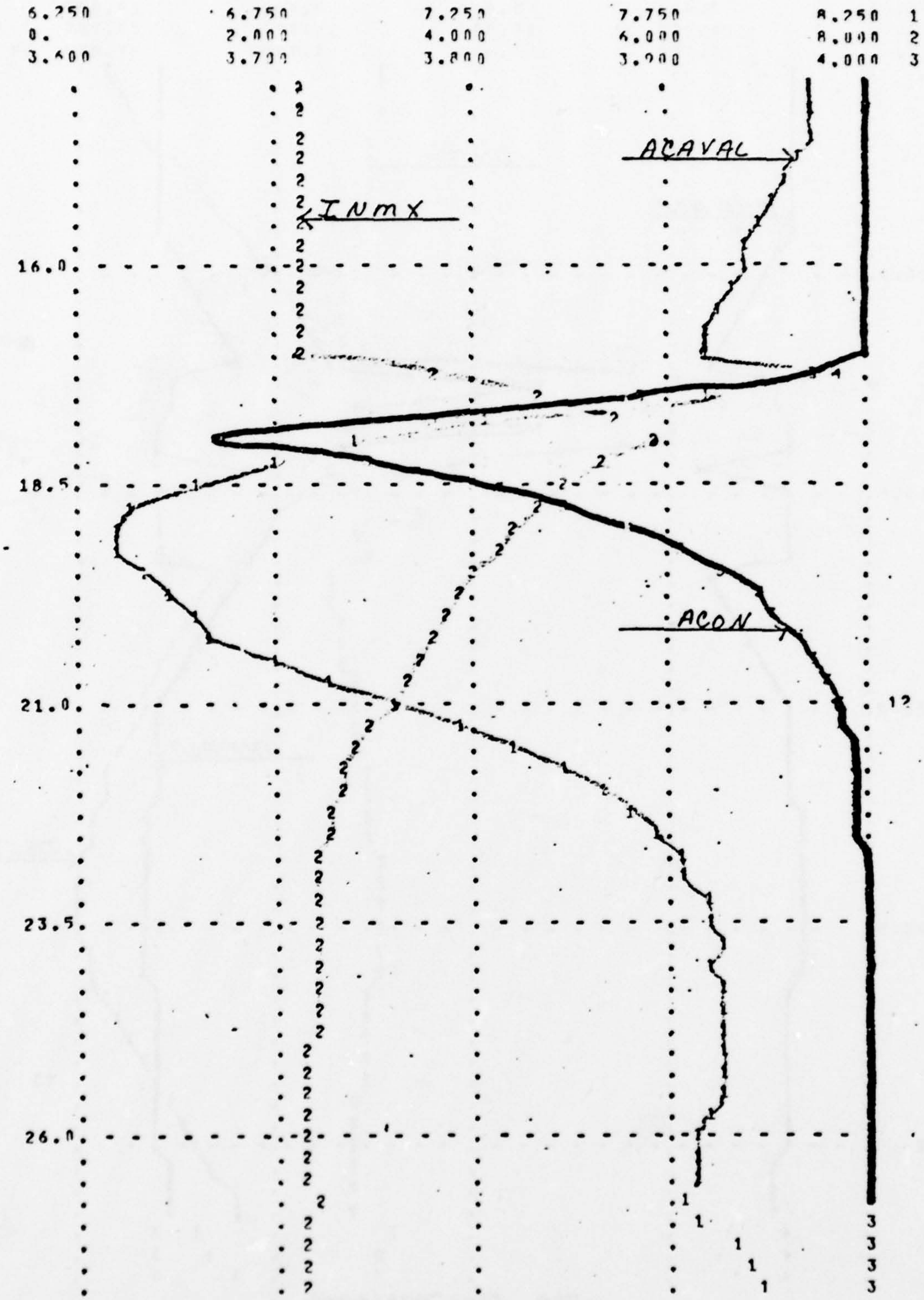

Fig. 48--Continued

PAGE 5 WING LEVEL SCHEDULING--A SYSTEMIC MODEL. EXLOSS
ACAVLF=1 ACSCHF=2 FLYAC=3

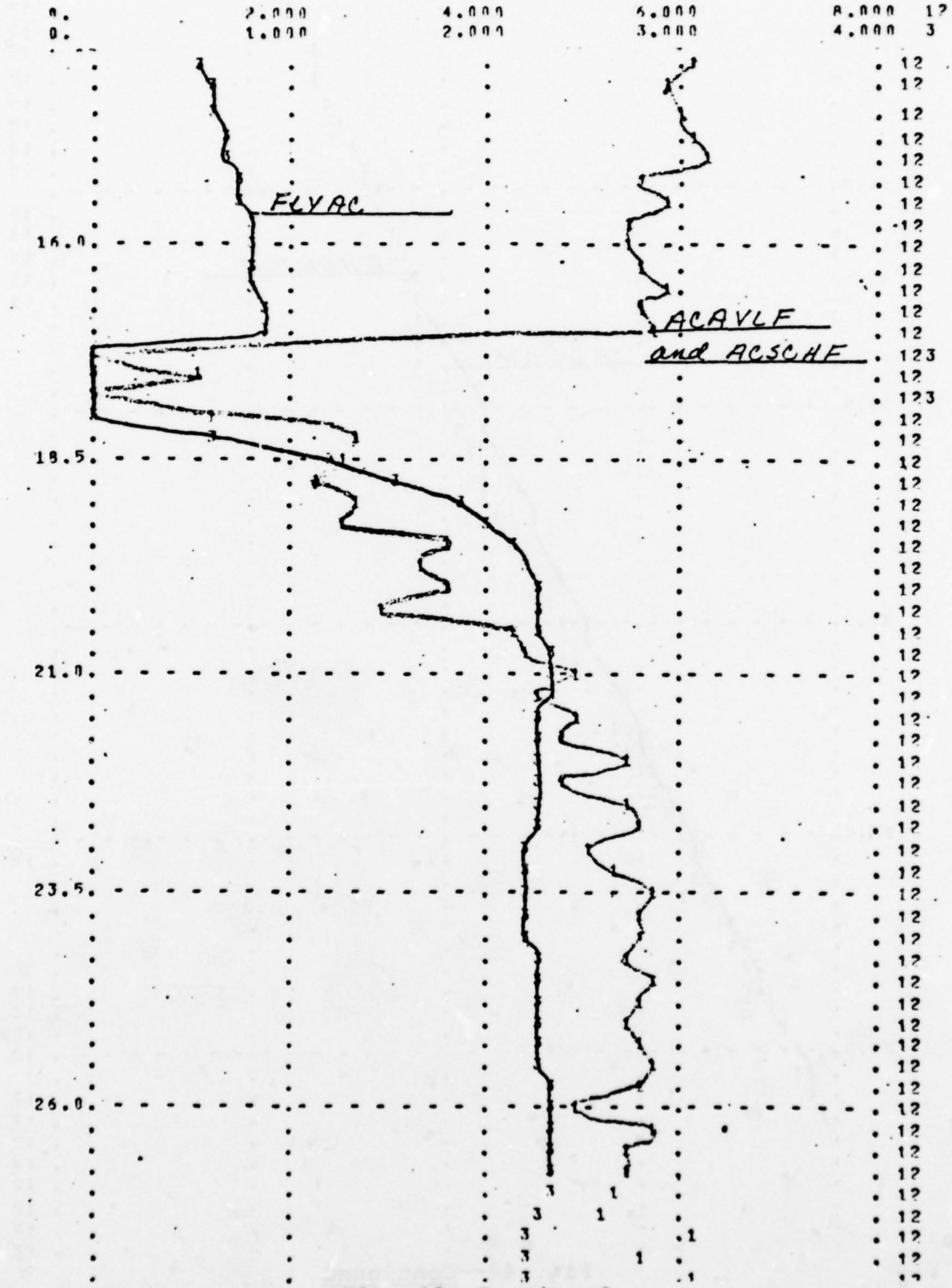

Fig. 48--Continued

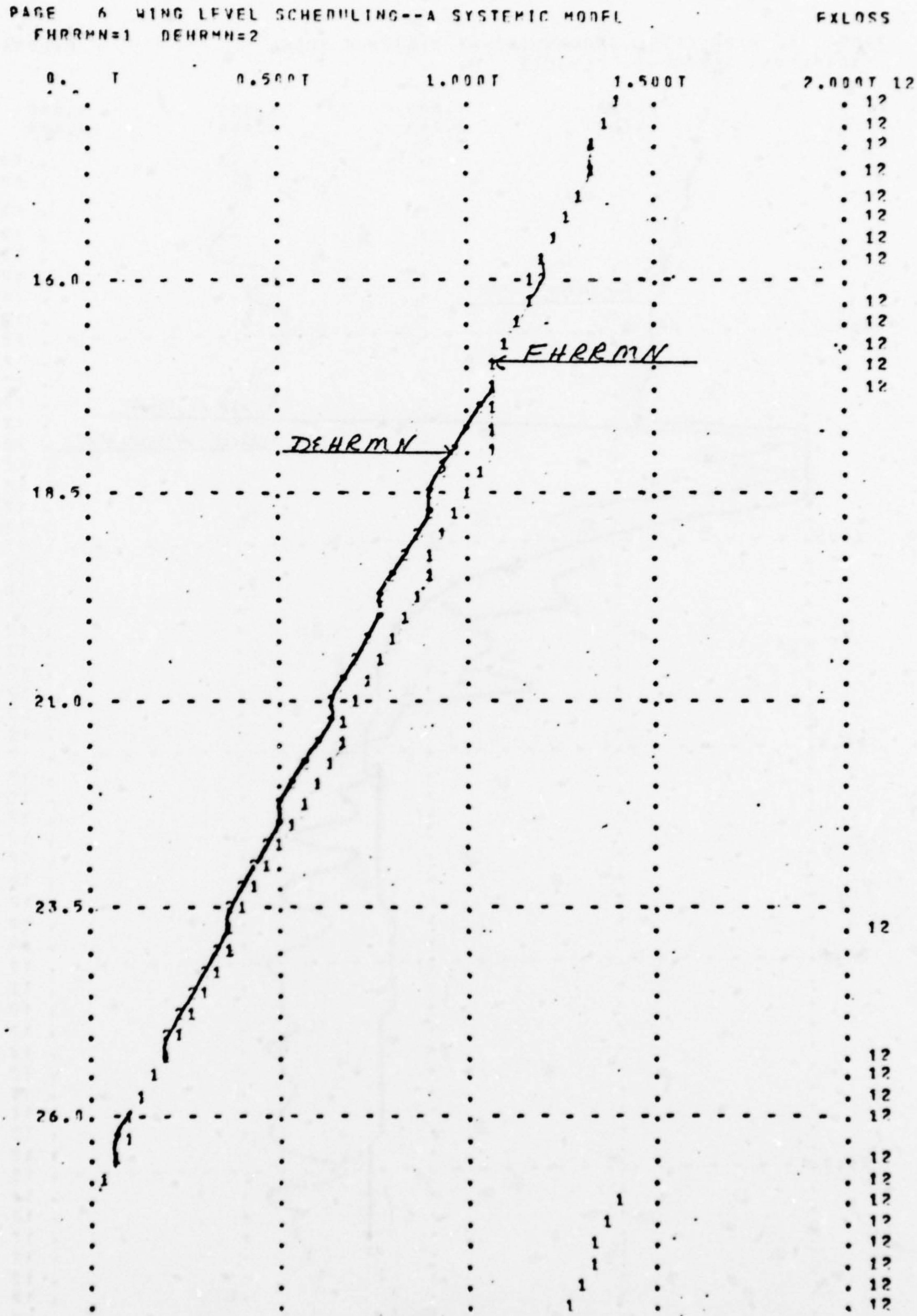

Fig. 48--Continued

PAGE 7 WING LEVEL SCHEDULING--A SYSTEMIC MODEL EXLOSS
OPSORL=1 MXSORL=2 DESHRS=3

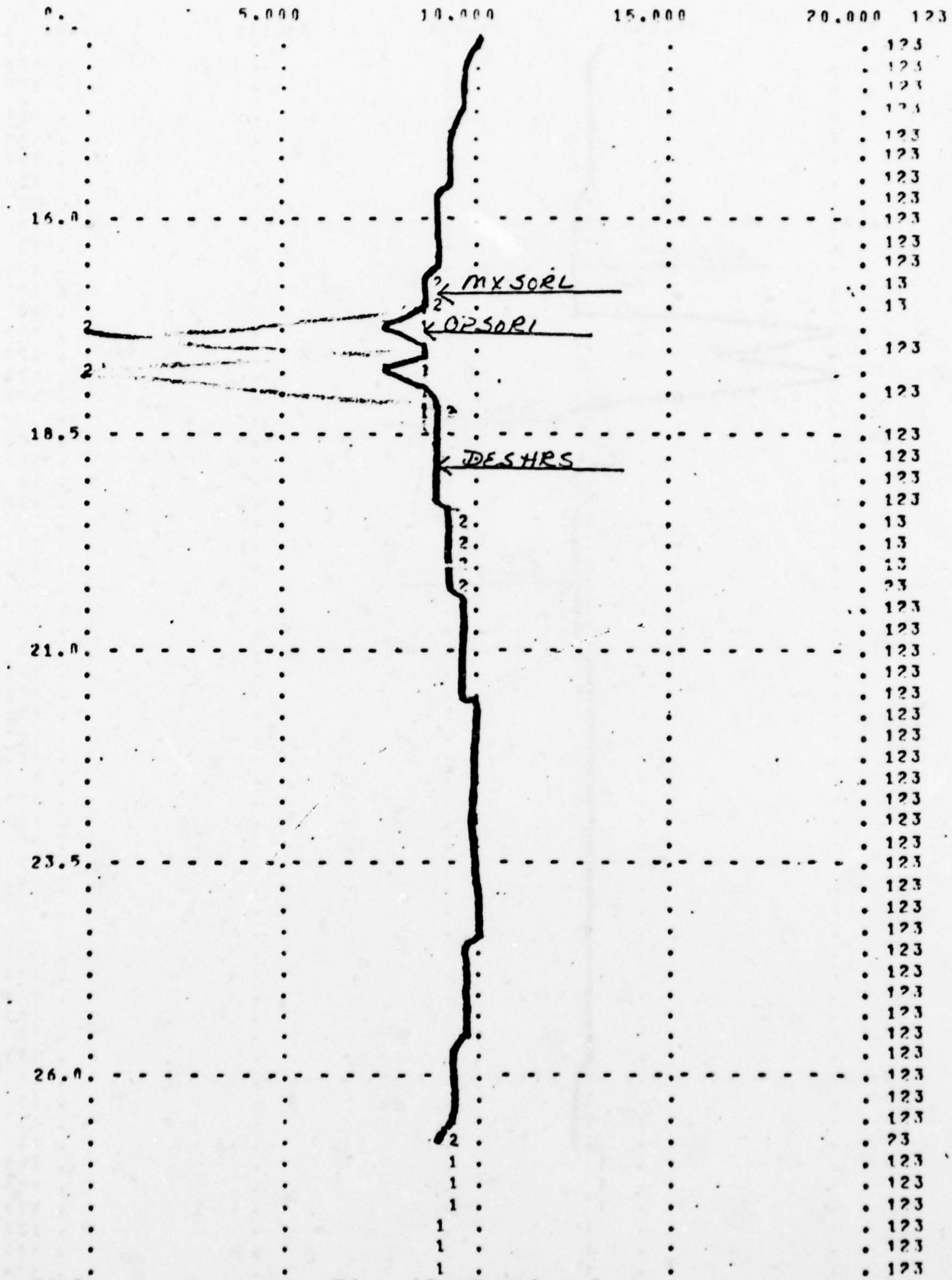

Fig. 48--Continued

PAGE 8 WING LEVEL SCHEDULING--A SYSTEMIC MODEL EXLOSS
OPSORT=1 MXSORT=2 SORTIE=3

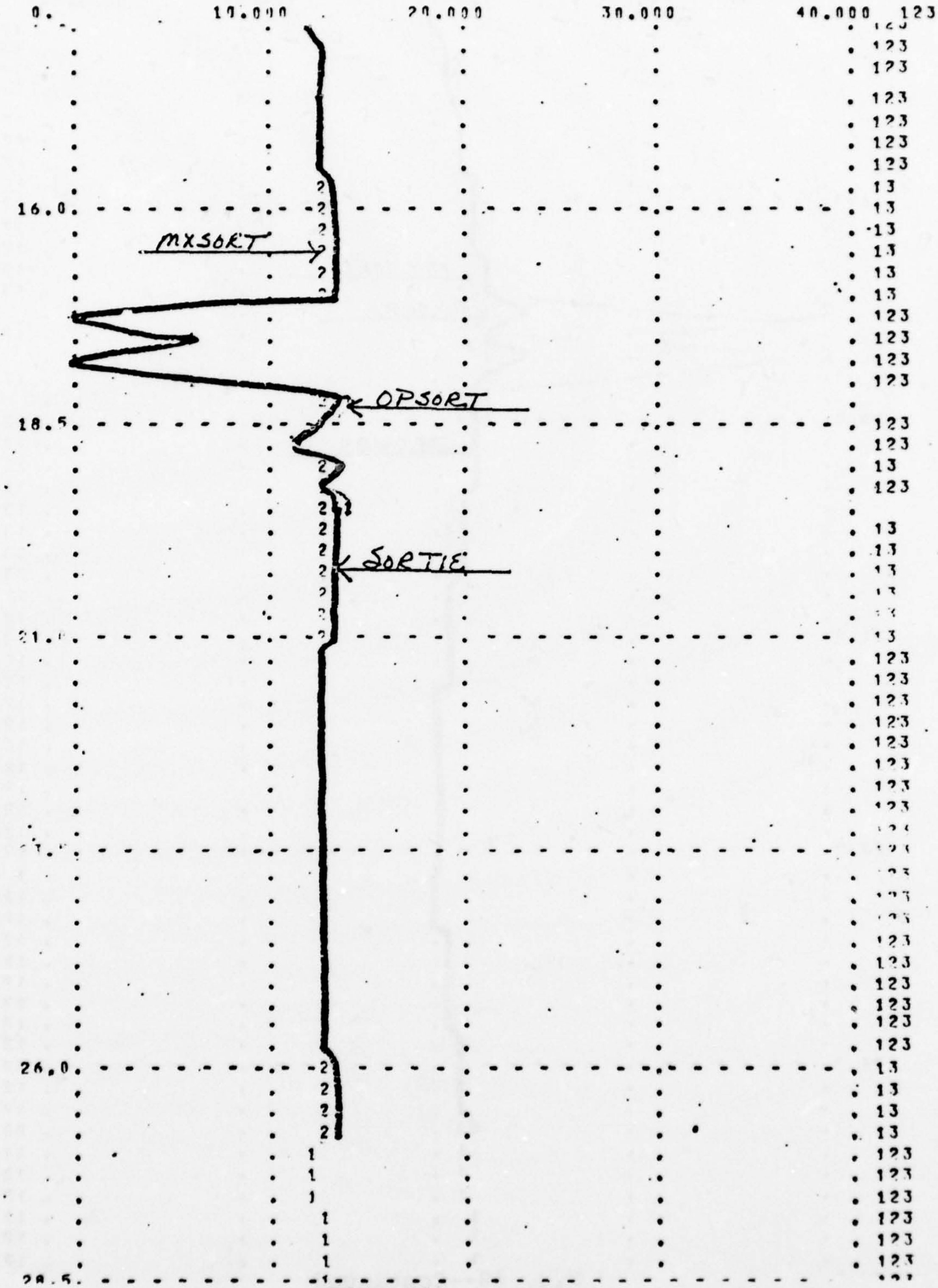

Fig. 48--Continued

PAGE 9 WING LEVEL SCHEDULING--A SYSTEMIC MODEL EXLOSS
OPFACR=1 MXFACR=2 UREOOP=3

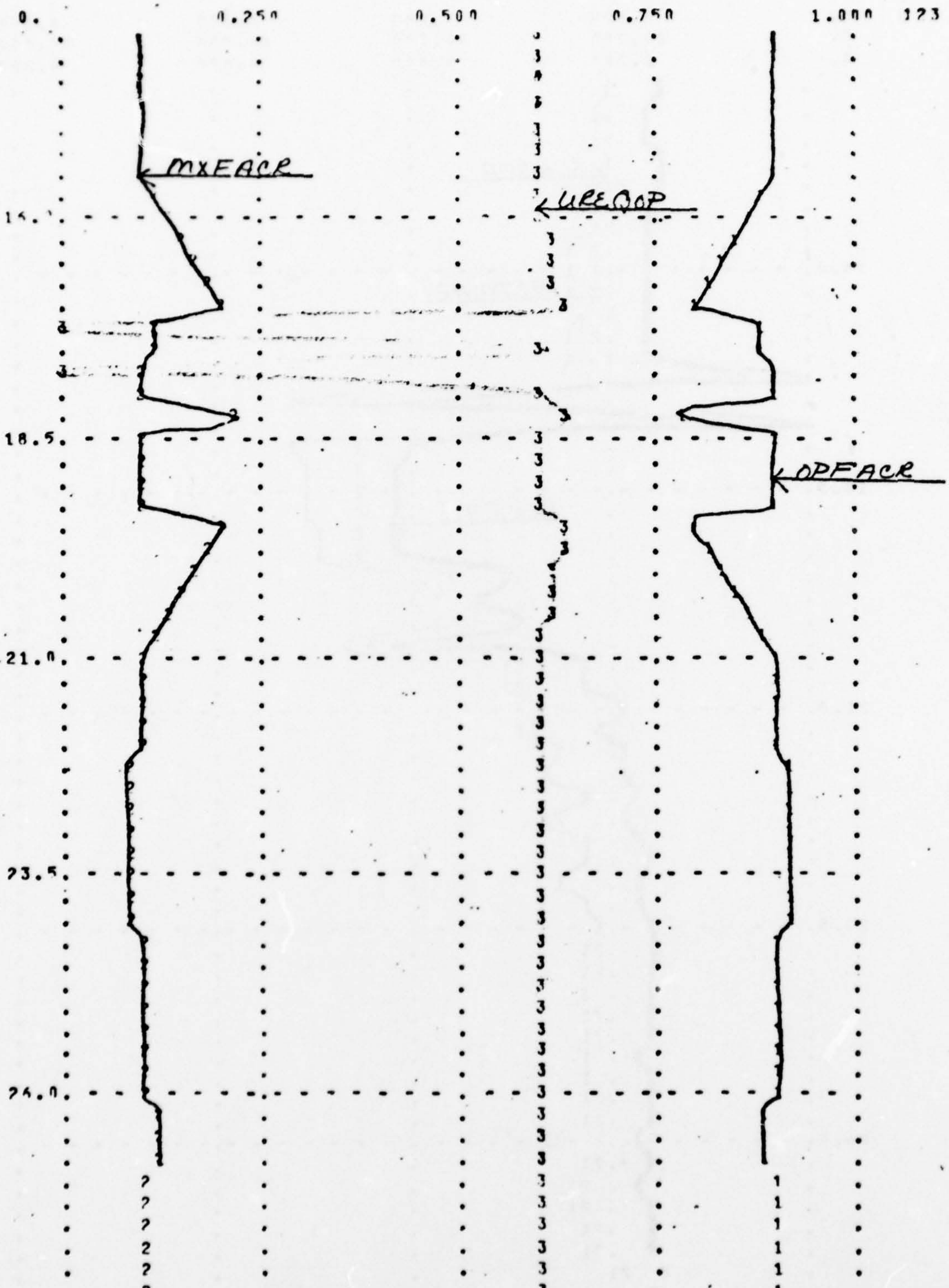

Fig. 48--Continued

PAGE 10 WING LEVEL SCHEDULING--A SYSTEMIC MODEL EXLOSS
SCHSPA=1 ACTMHR=2 BRKRTE=3

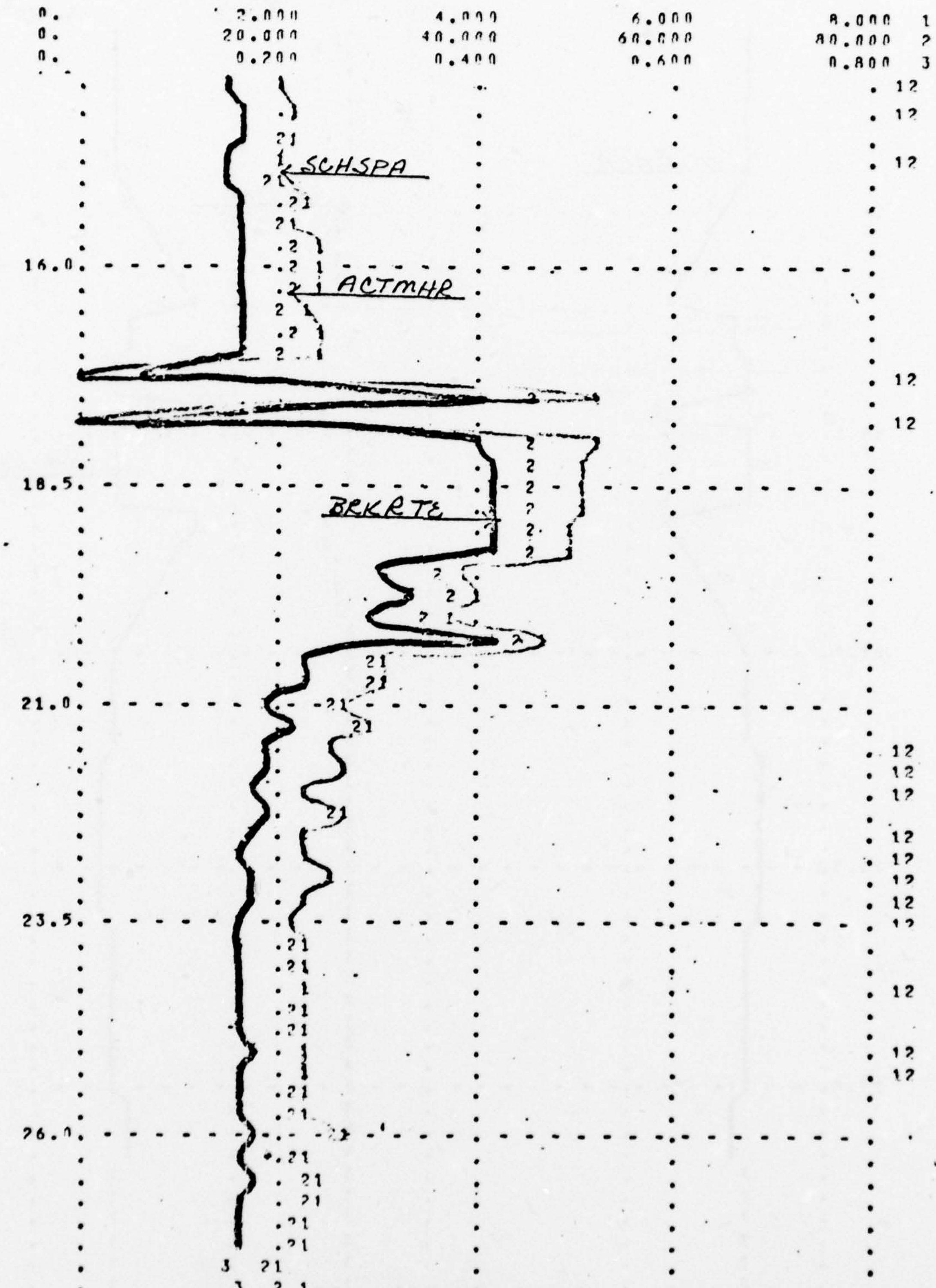

Fig. 48--Continued

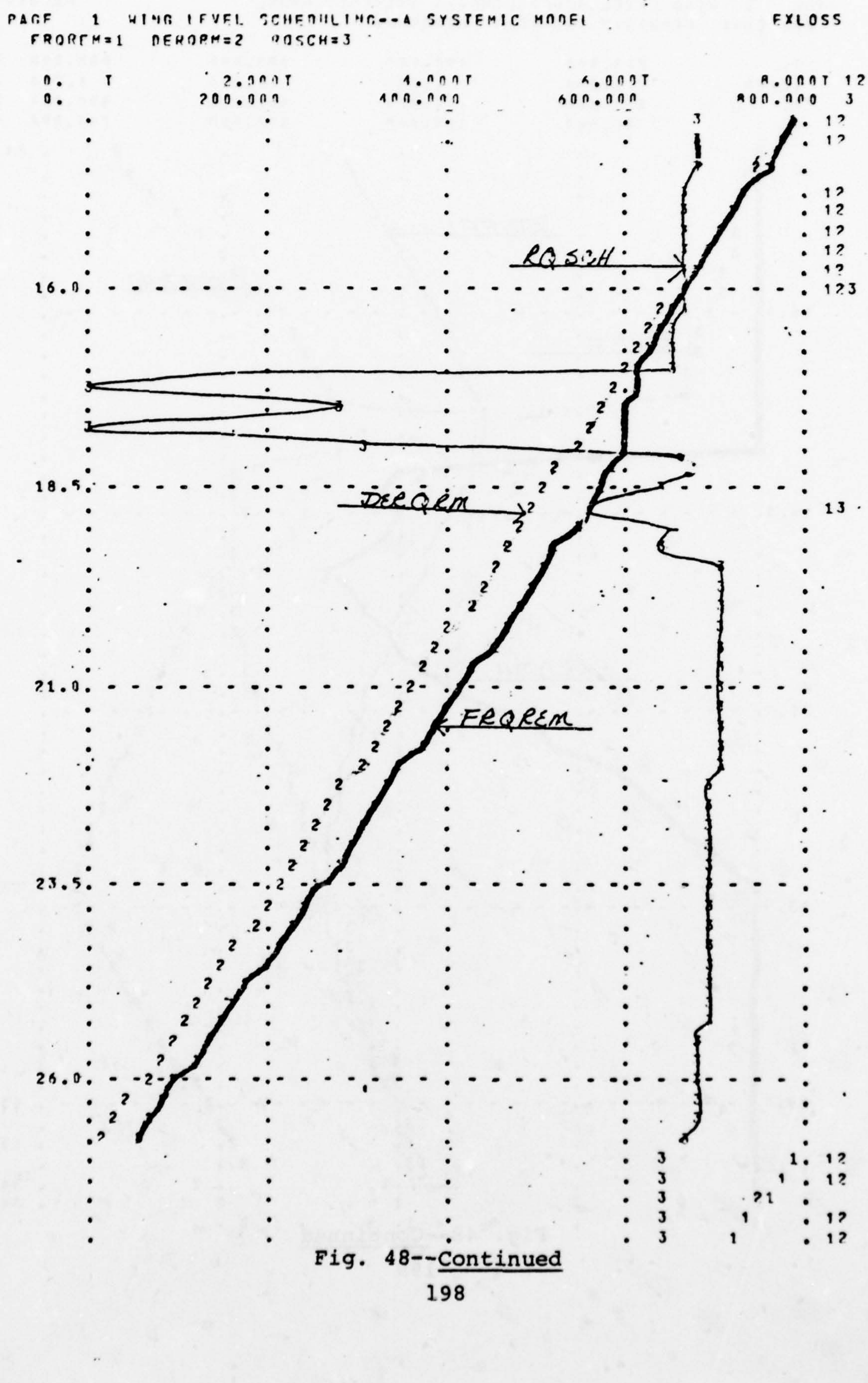

Fig. 48--Continued

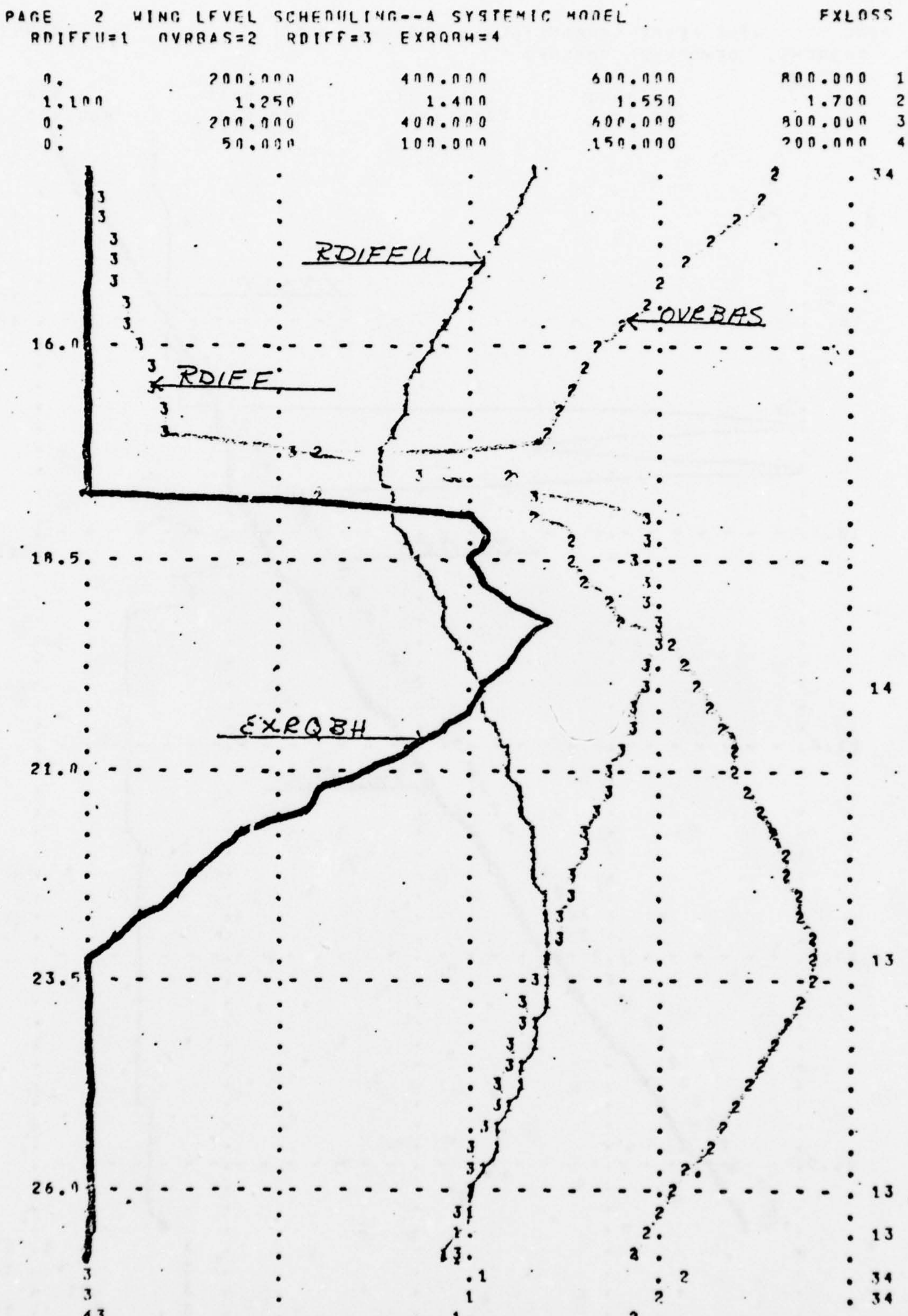

Fig. 48--Continued

PAGE 3 WING LEVEL SCHEDULING--A SYSTEMIC MODEL EXLOSS
OPCAVL=1 COAL=2 OPAVLF=3 FLYCRS=4

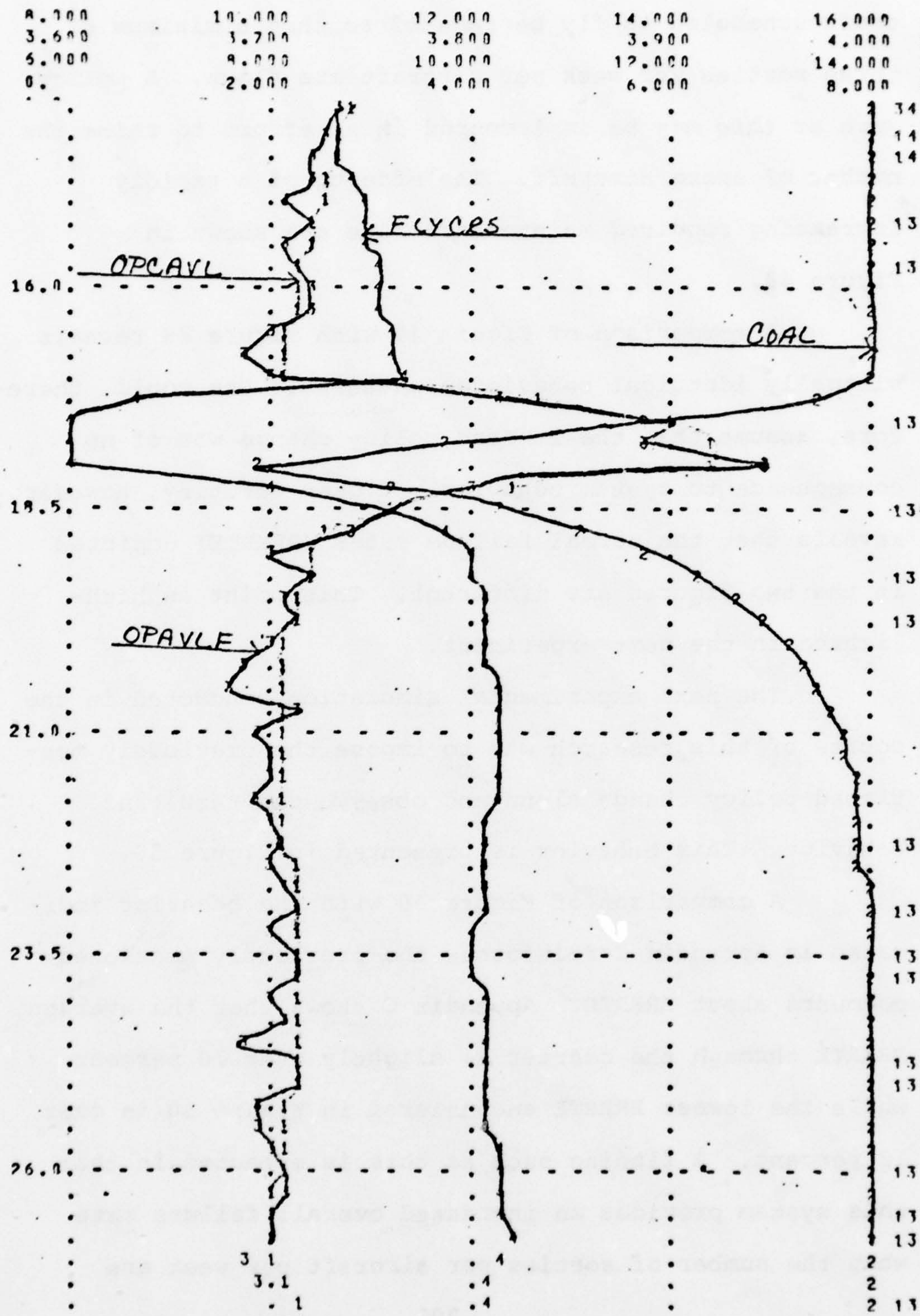

Fig. 48--Continued

system. The new policy mandated that the number of aircraft scheduled to fly be reduced so that a minimum of three sorties per week per aircraft are flown. A policy such as this may be implemented in an effort to raise the number of spare aircraft. The effects of a rapidly increasing required maintenance rate are shown in Figure 49.

A comparison of Figure 49 with Figure 48 reveals virtually identical behavioral patterns. One could, therefore, assume that the imposed policy change was of no consequence to system behavior. Closer scrutiny, however, reveals that the normal failure rates (BRKRTE) depicted in the two figures are different. This point is highlighted in the next experiment.

The next experimental simulation conducted in the course of this research was to impose the previously mentioned policy change alone and observe the resultant behavior. This behavior is presented in Figure 50.

A comparison of Figure 50 with the behavior indicated in Appendix C reinforces the previously mentioned comments about BRKRTE. Appendix C shows that the average BRKRTE through the quarter is slightly over 16 percent while the lowest BRKRTE encountered in Figure 50 is over 18 percent. A finding such as this is expected in that this system provides an increased overall failure rate when the number of sorties per aircraft per week are

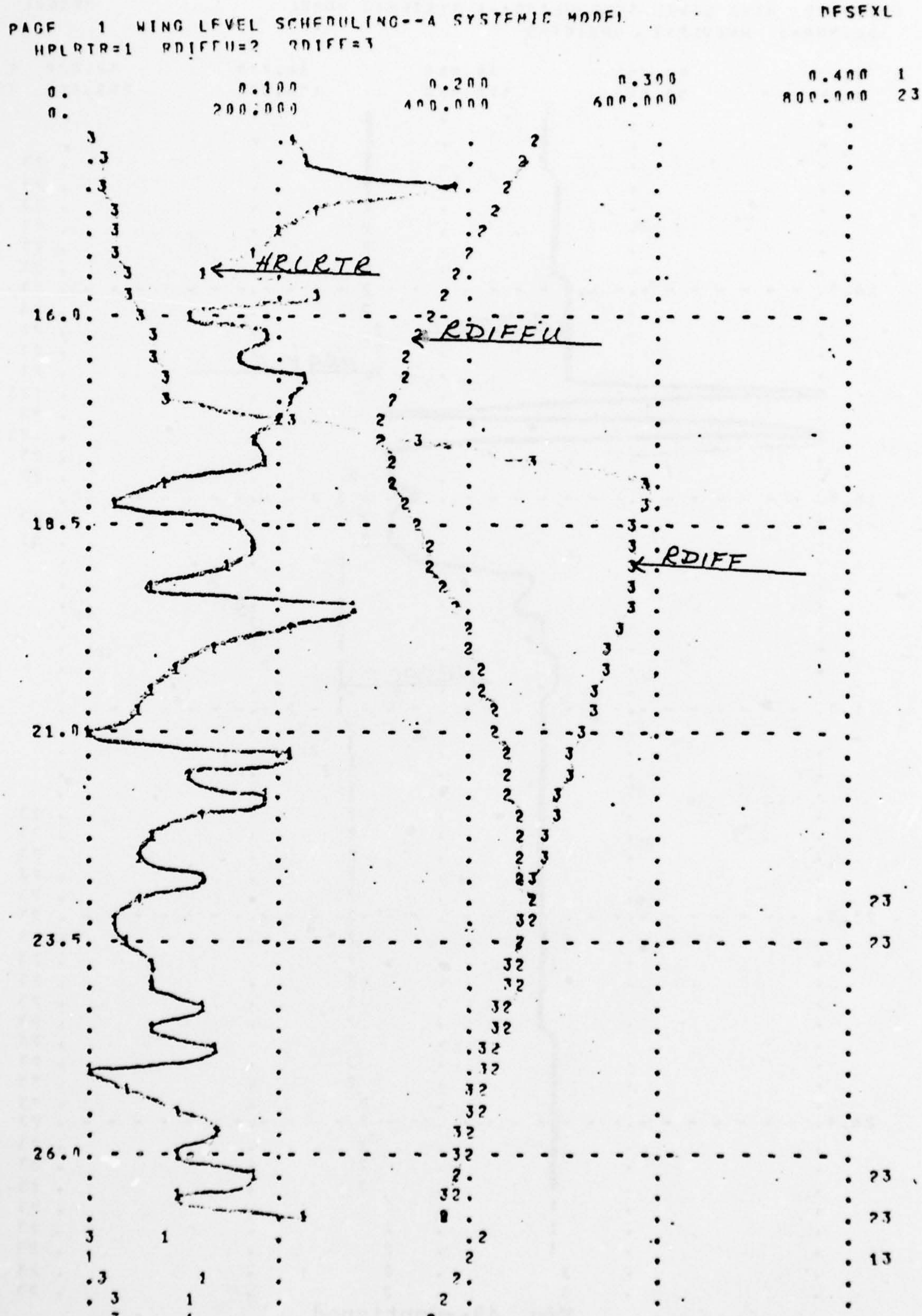

Fig. 49. Plots for Experiment 3

PAGE 2 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESEXL

ACTMHR=1 HRAVLF=2 HRSACT=3

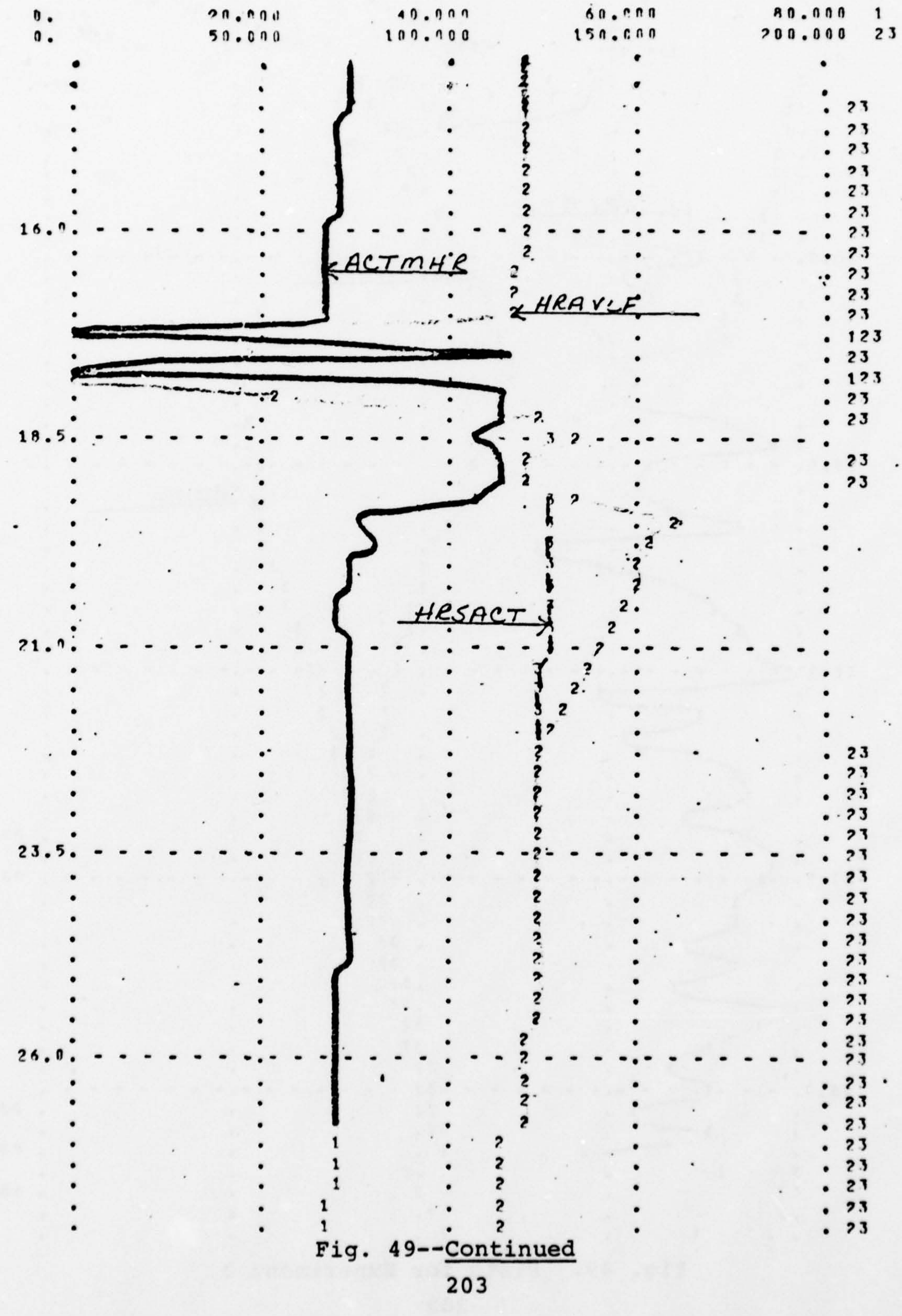

Fig. 49--Continued

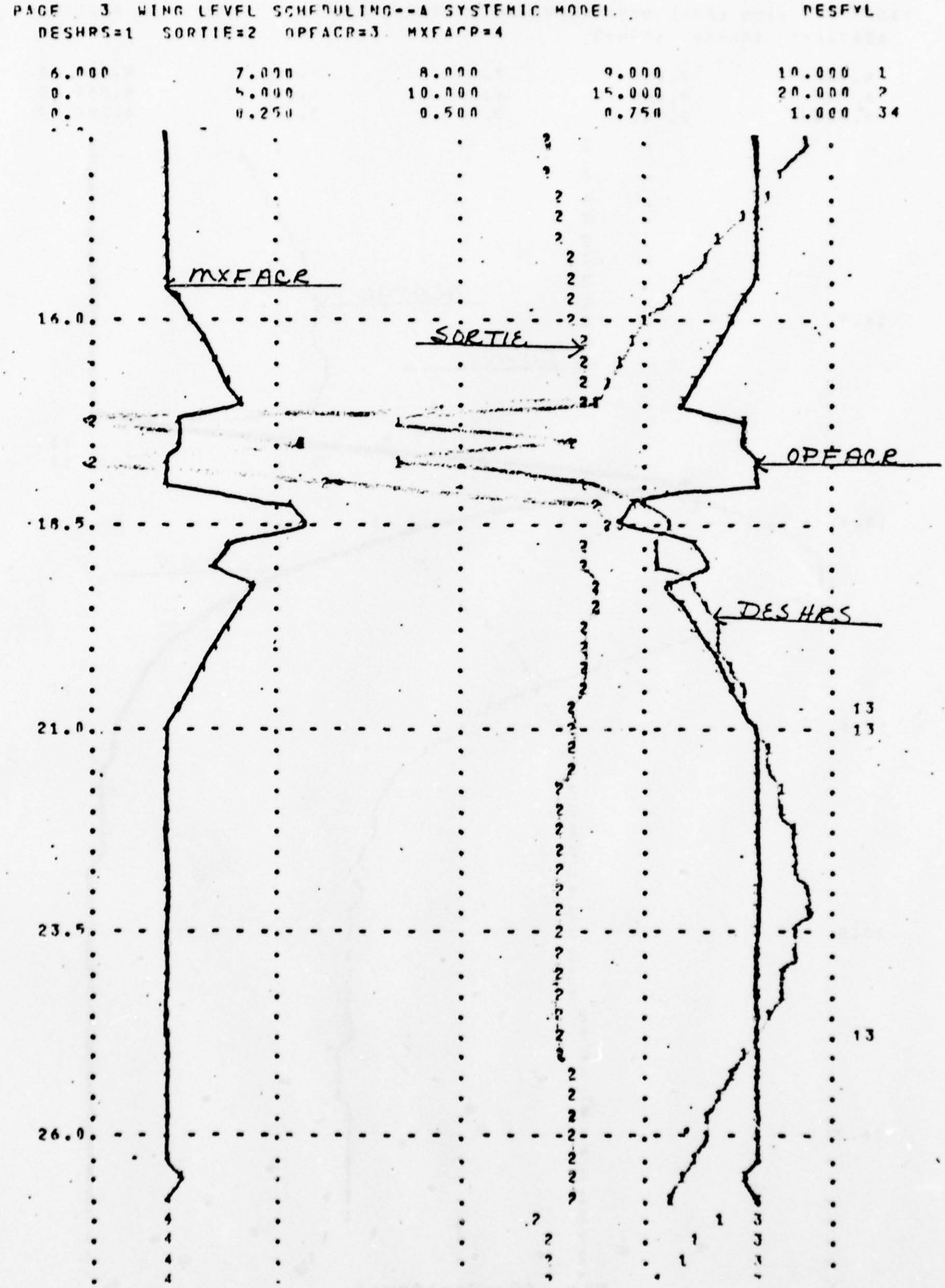

Fig. 49--Continued

PAGE 4 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESEXL
ACAVAL=1 INMX=2 ACON=3

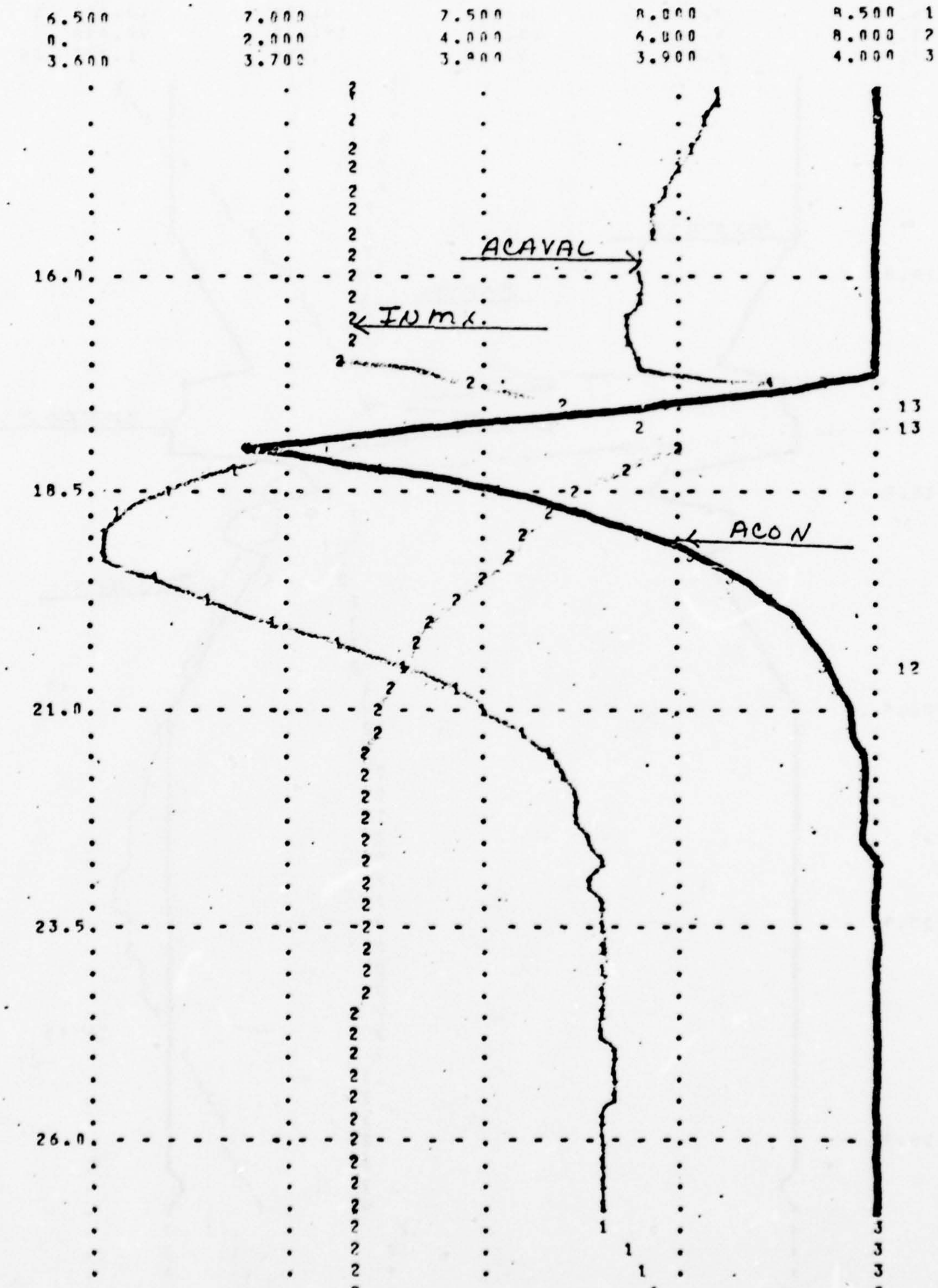

Fig. 49--Continued

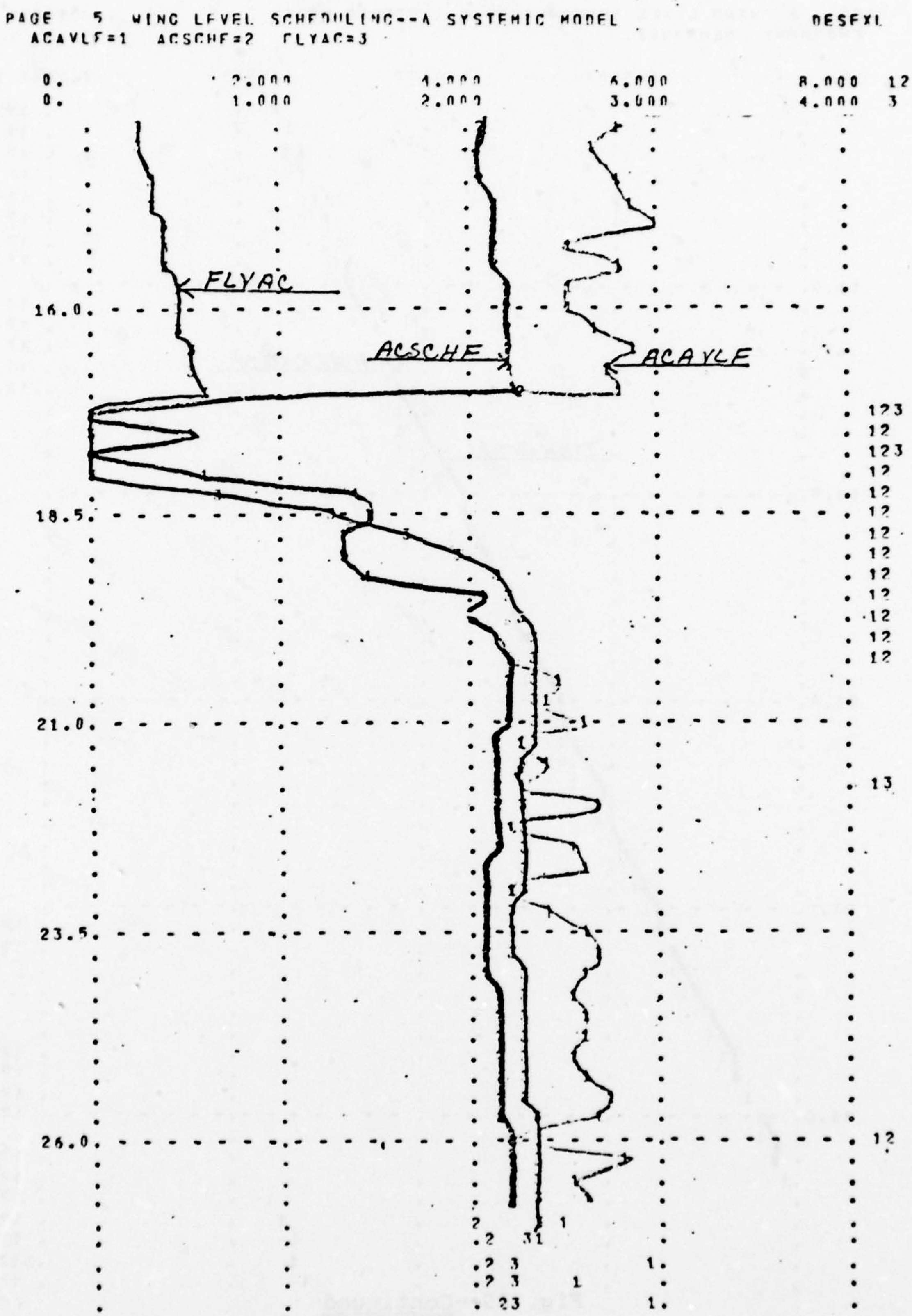

Fig. 49--Continued

FHRRMN=1 DEHRMN=2

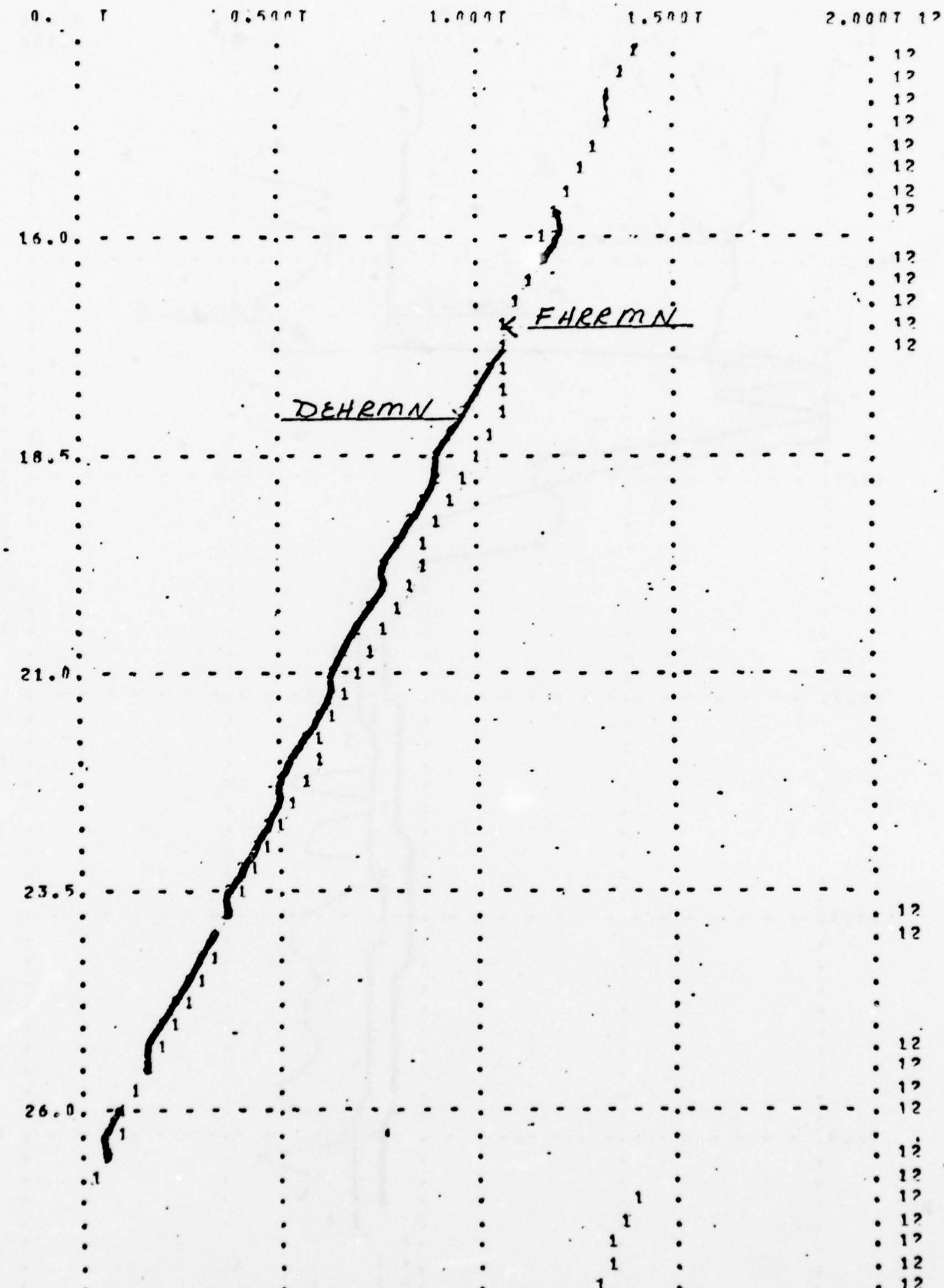

Fig. 49--Continued

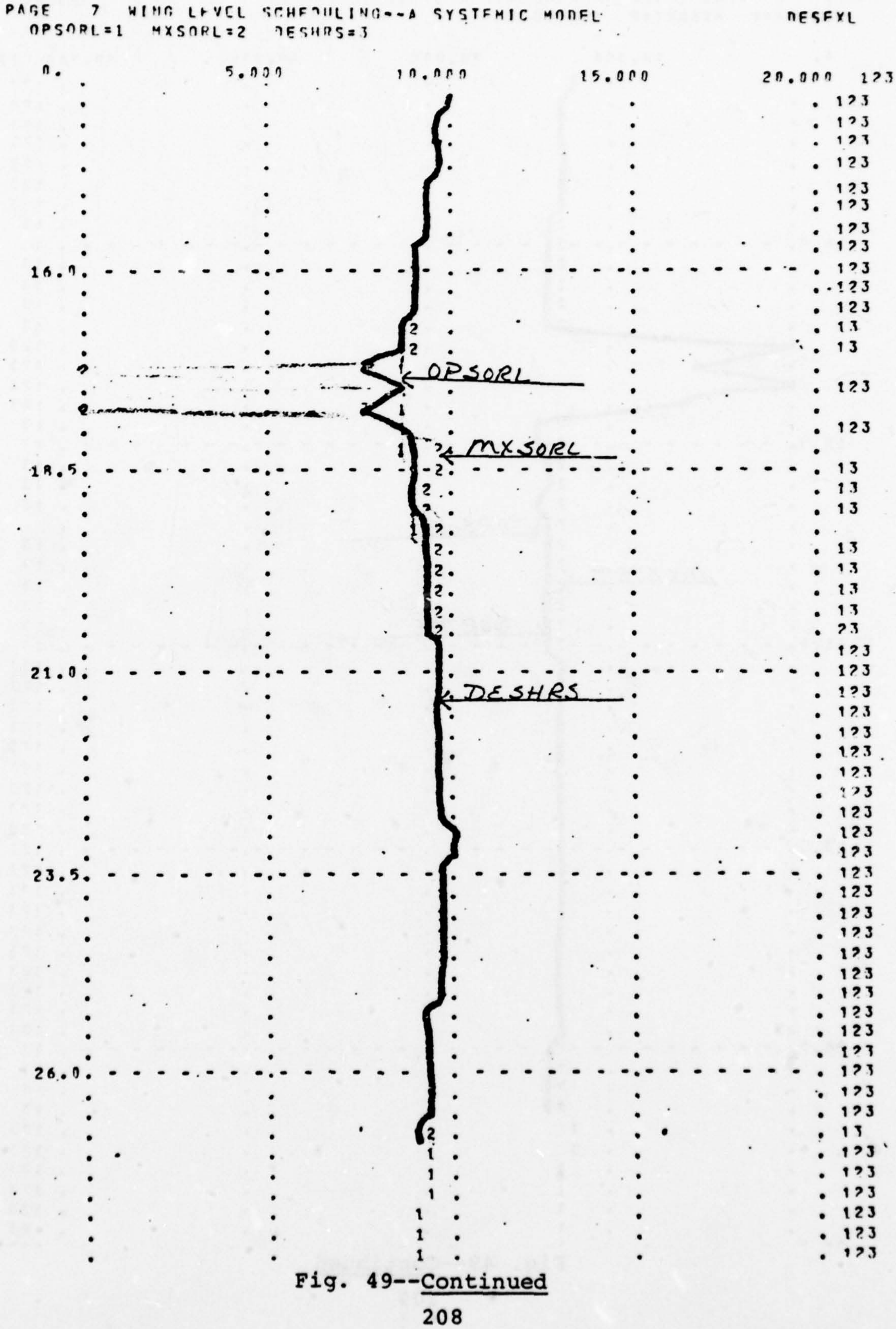

Fig. 49--Continued

PAGE 8 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESEXL
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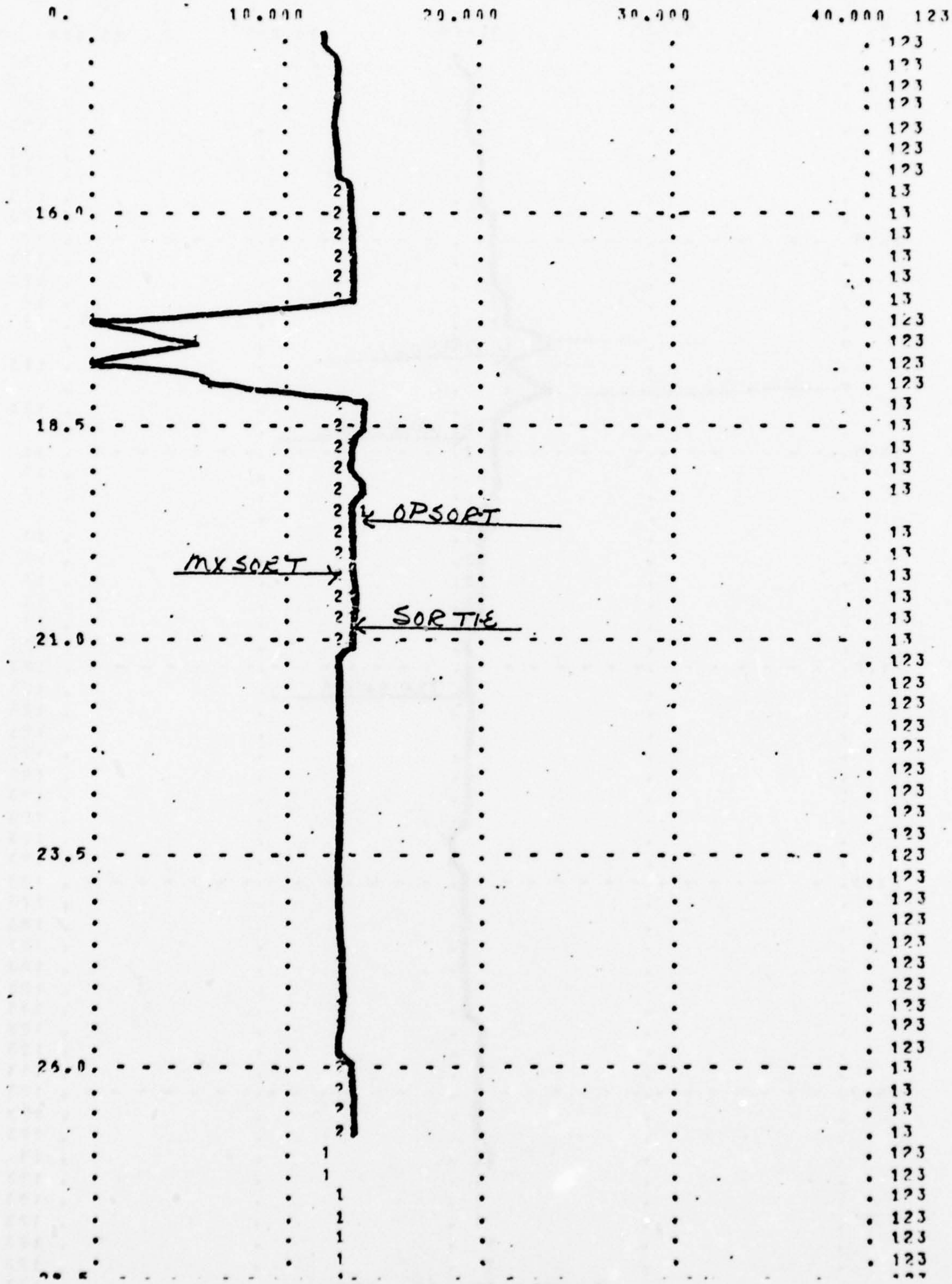

Fig. 49--Continued

PAGE 9 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESEXL
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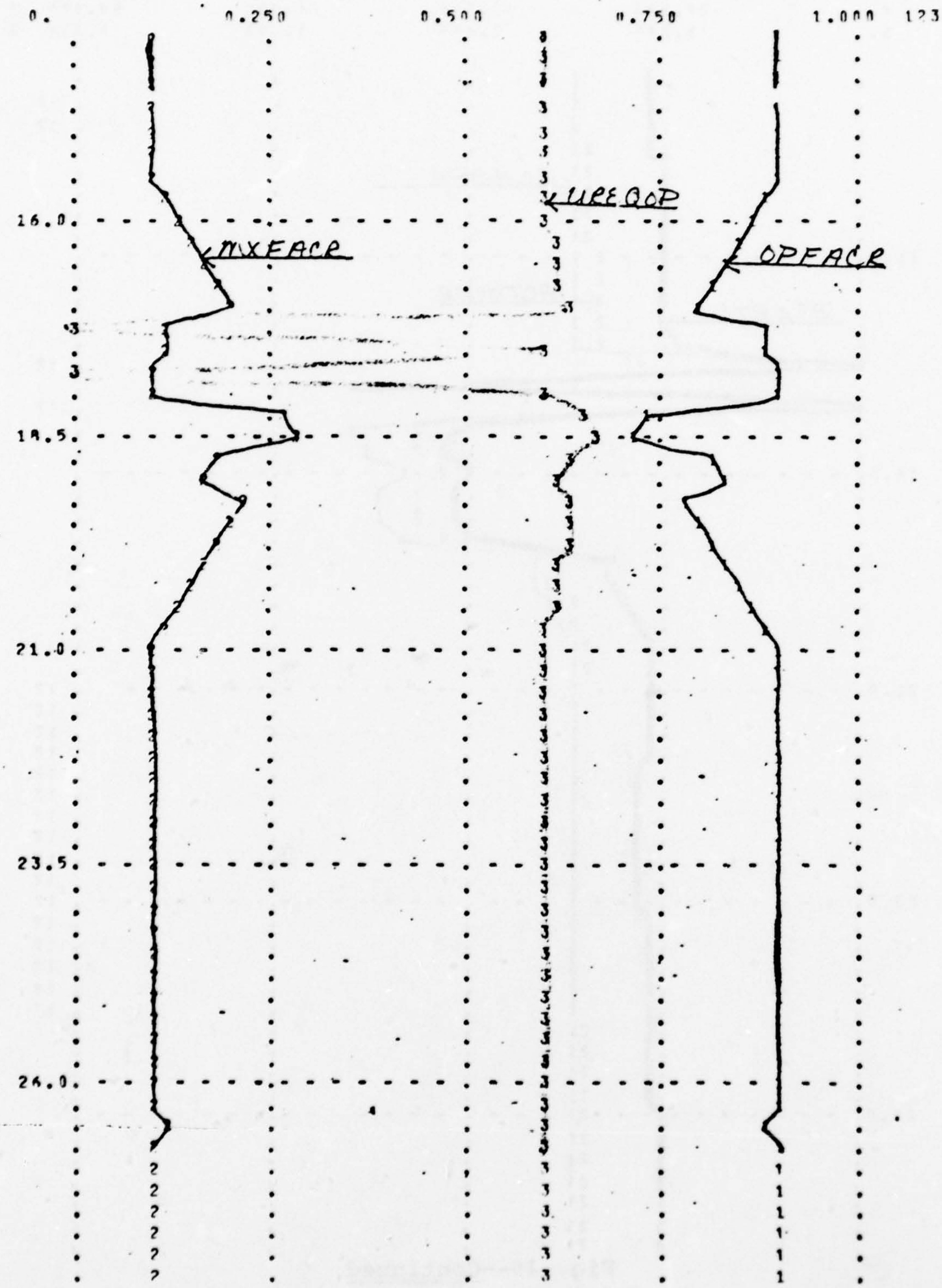

Fig. 49--Continued

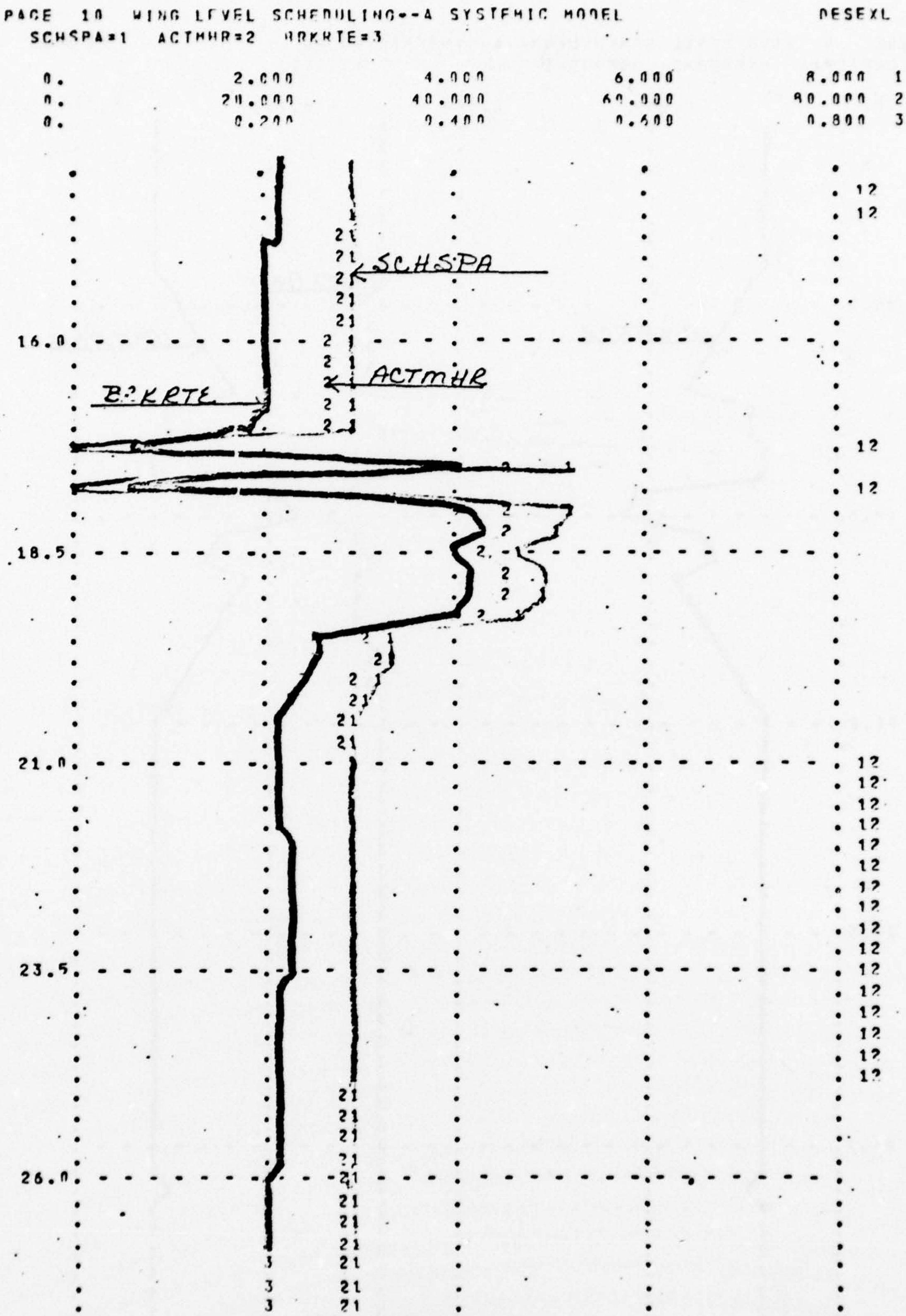

Fig. 49--Continued

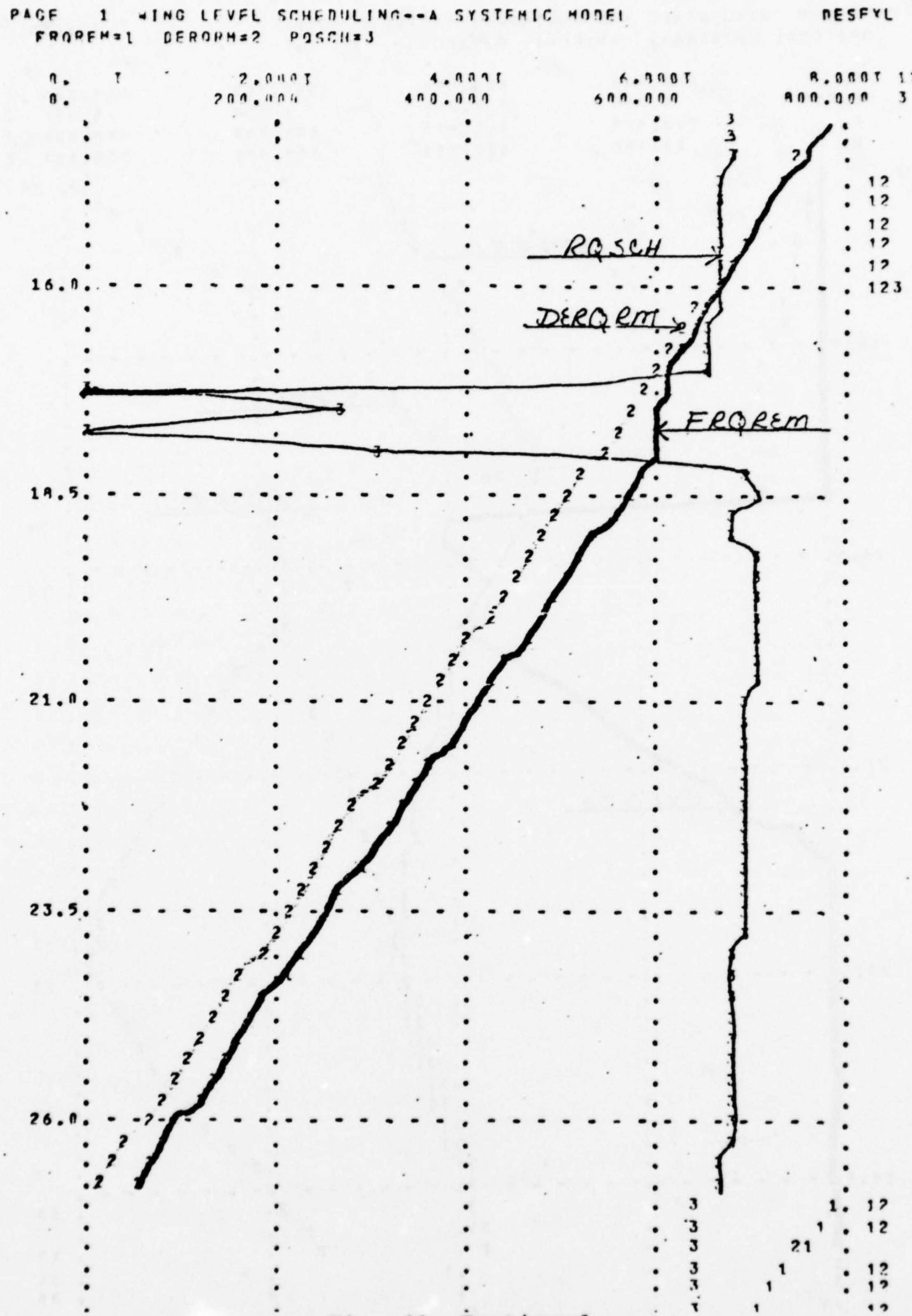

Fig. 49--Continued

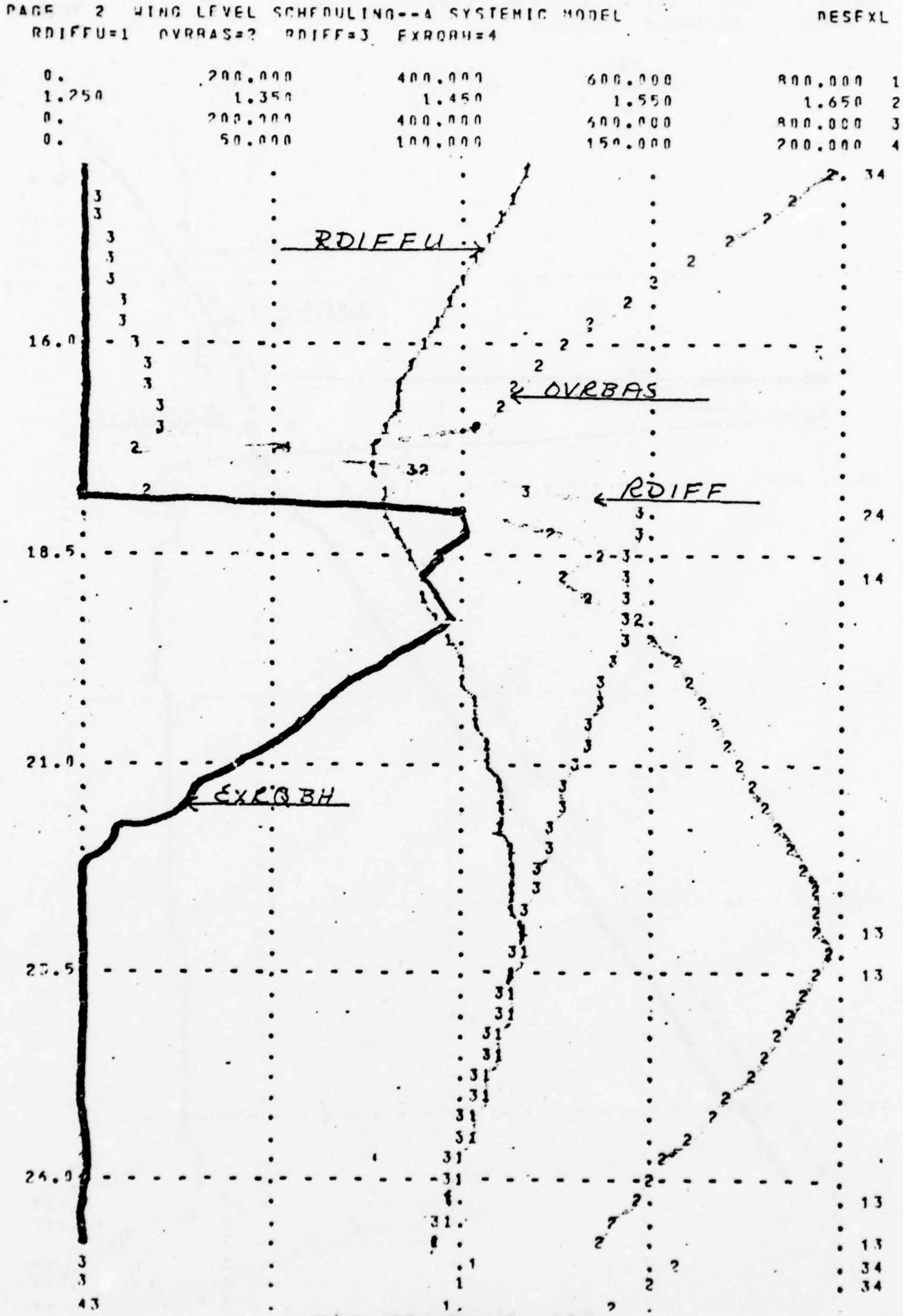

Fig. 49--Continued

PAGE 3 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESEXL
OPCAVL=1 COAL=2 OPAVLF=3 FLYCRS=4

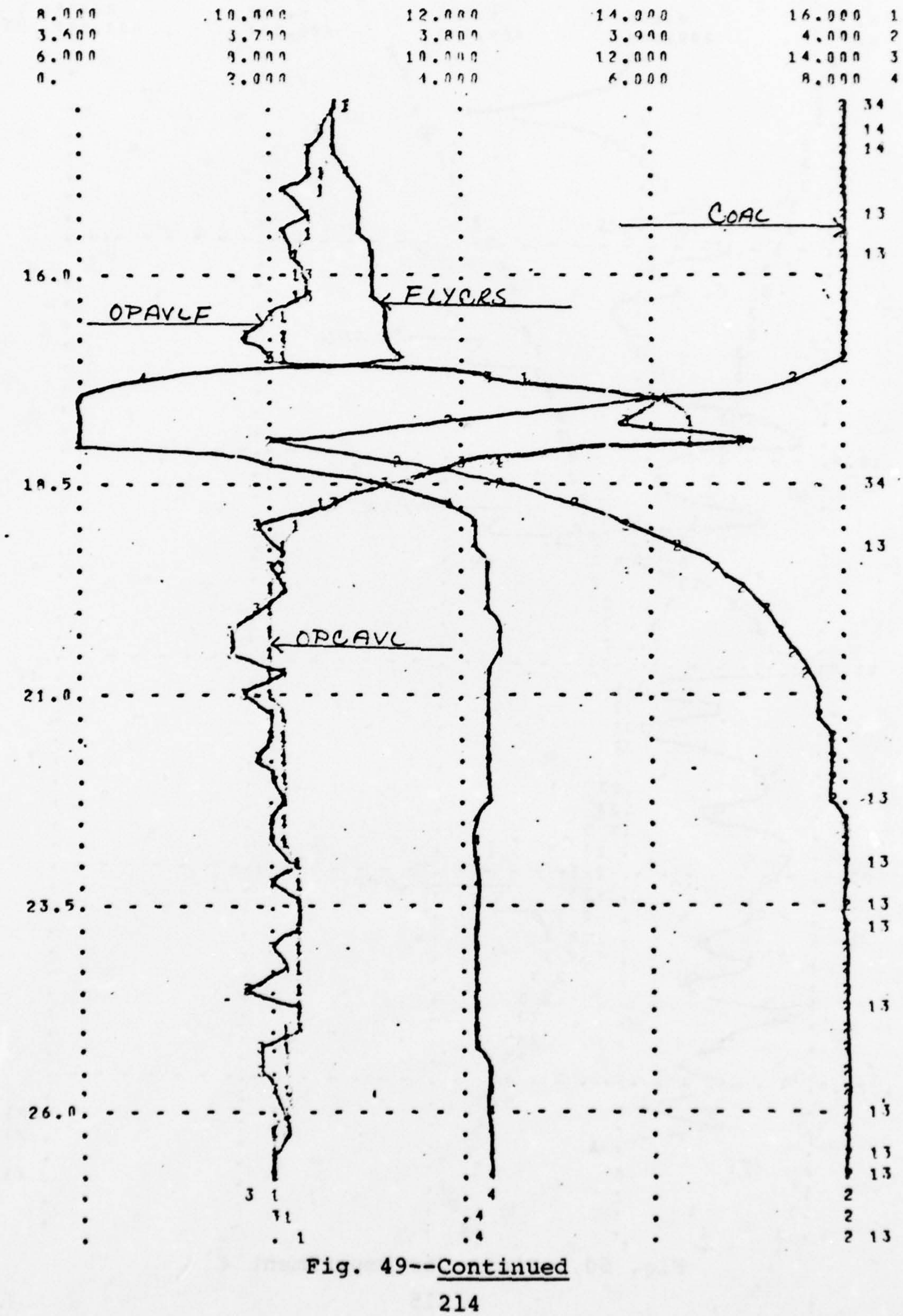

Fig. 49--Continued

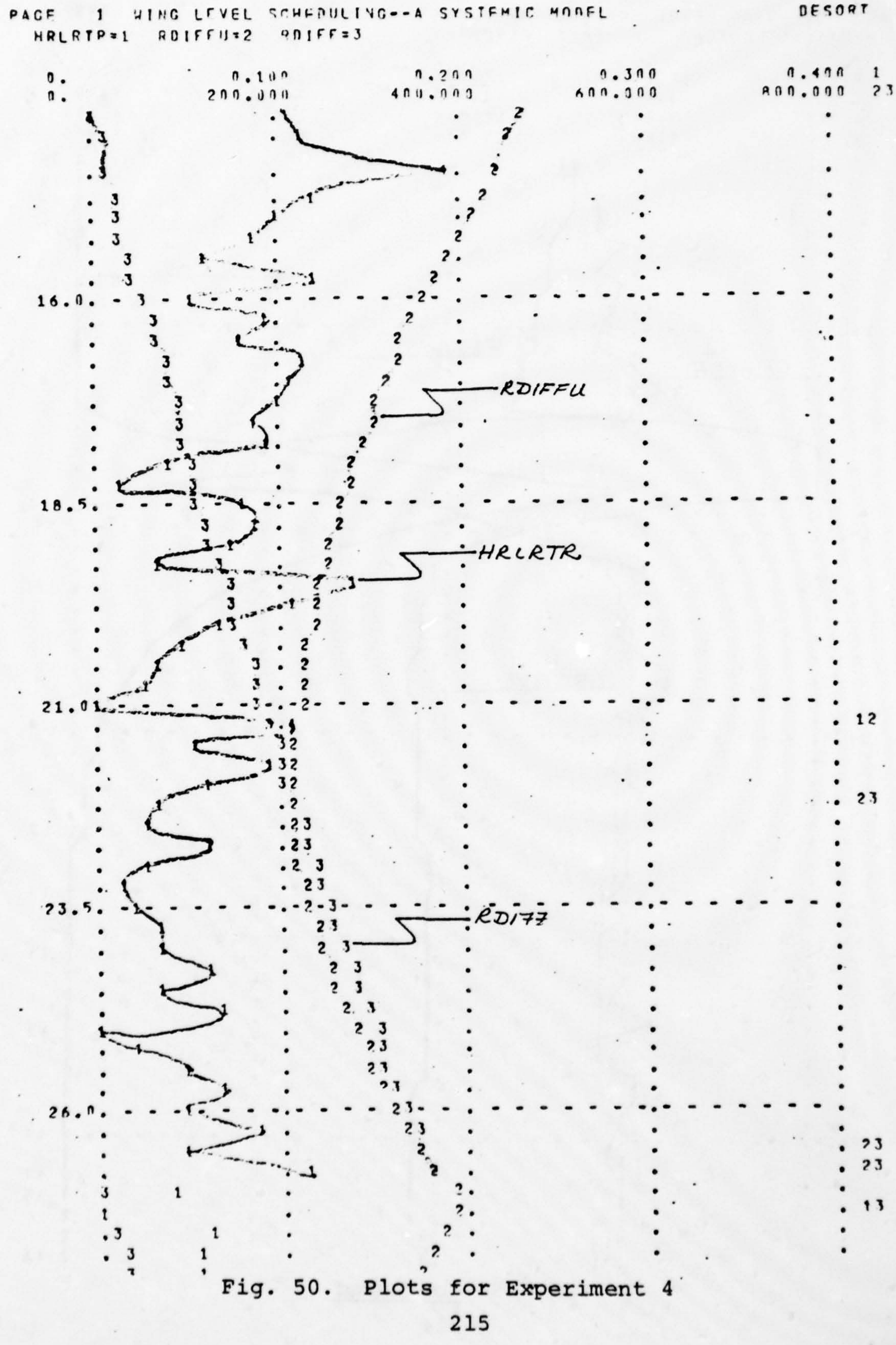

Fig. 50. Plots for Experiment 4

PAGE 2 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESORT
ACTMHR=1 HRAVLF=2 HRSACT=3

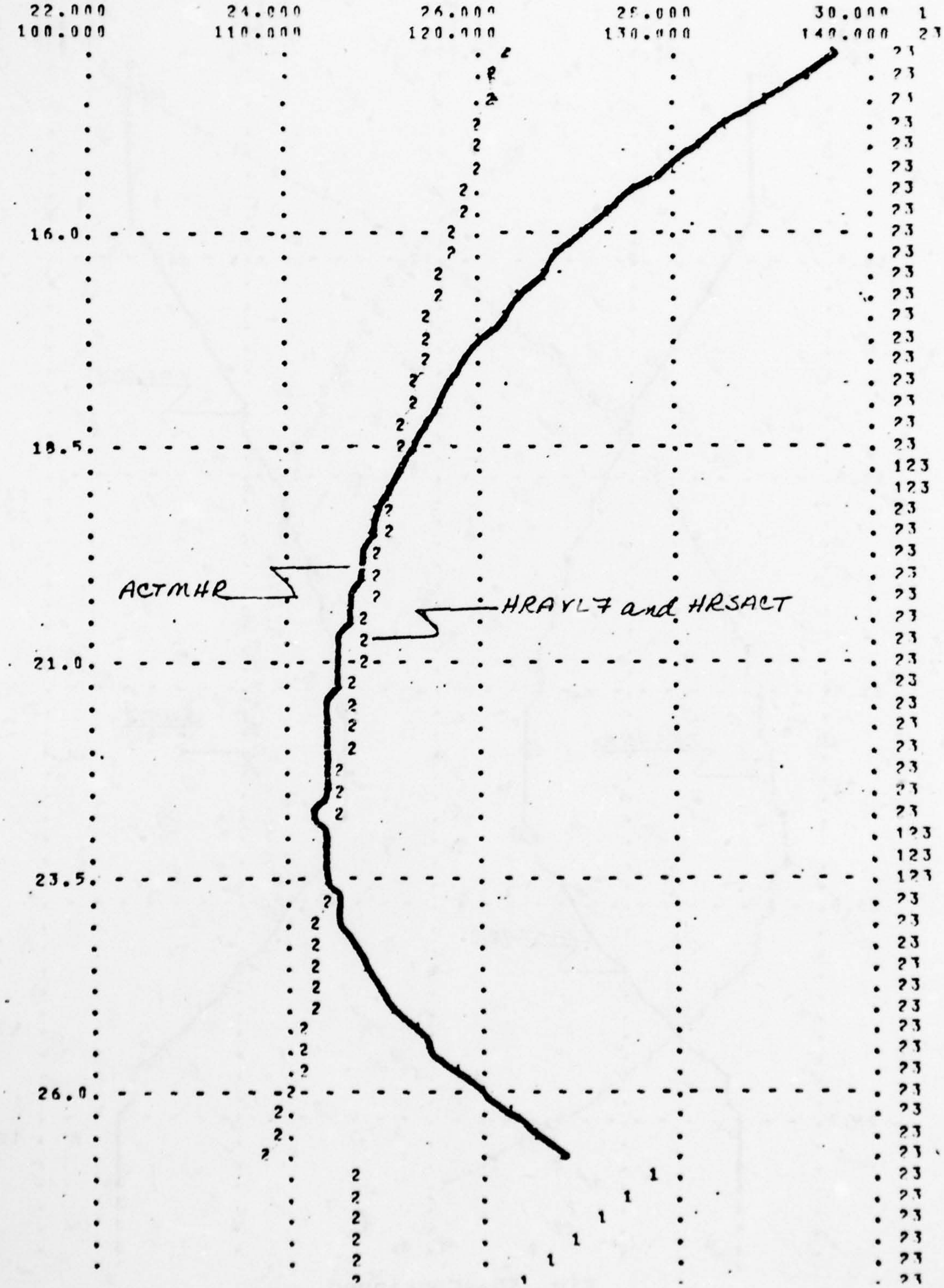

Fig. 50--Continued

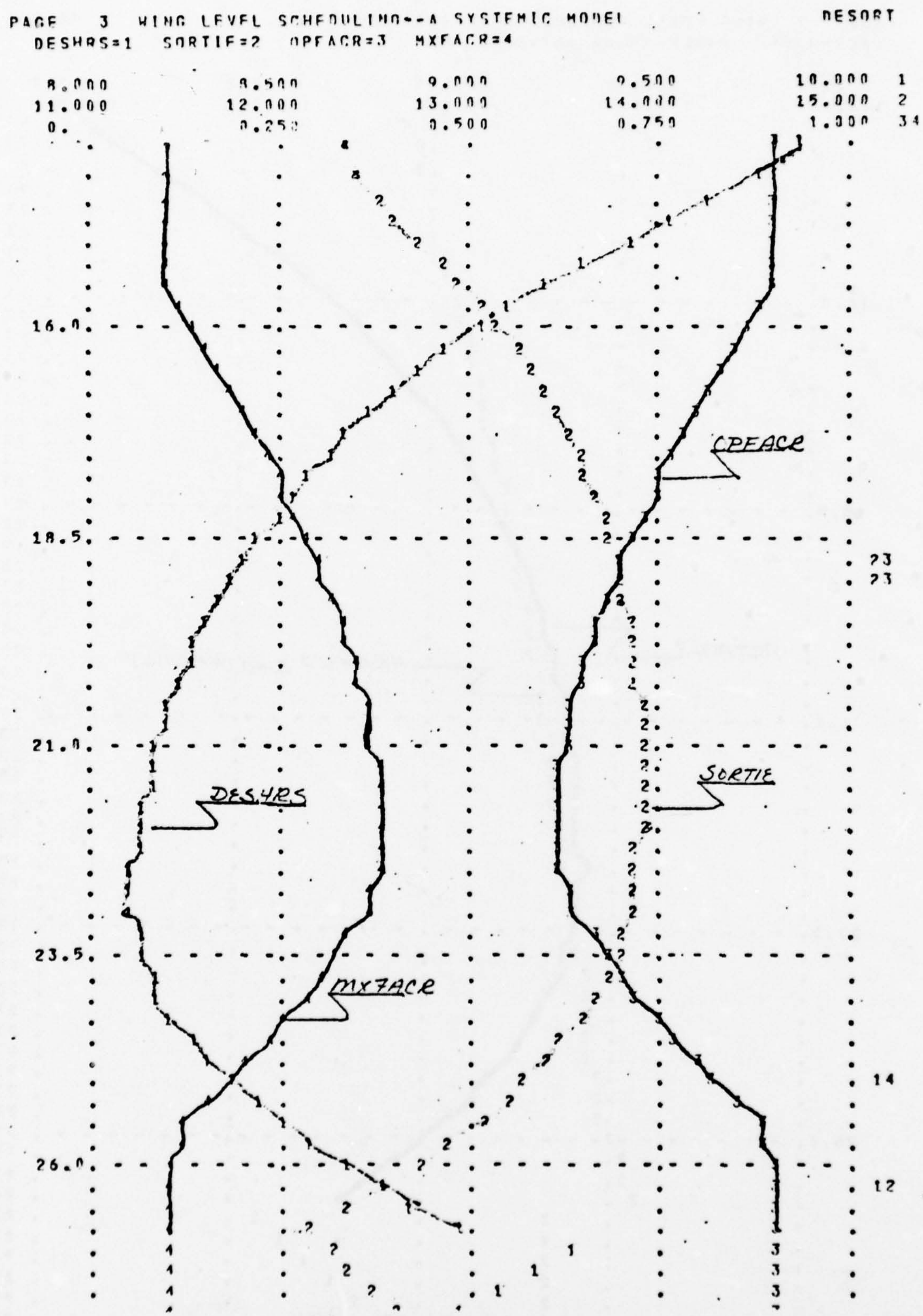

Fig. 50--Continued

PAGE 4 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESORT
ACAVAL=1 INMX=2 ACON=3

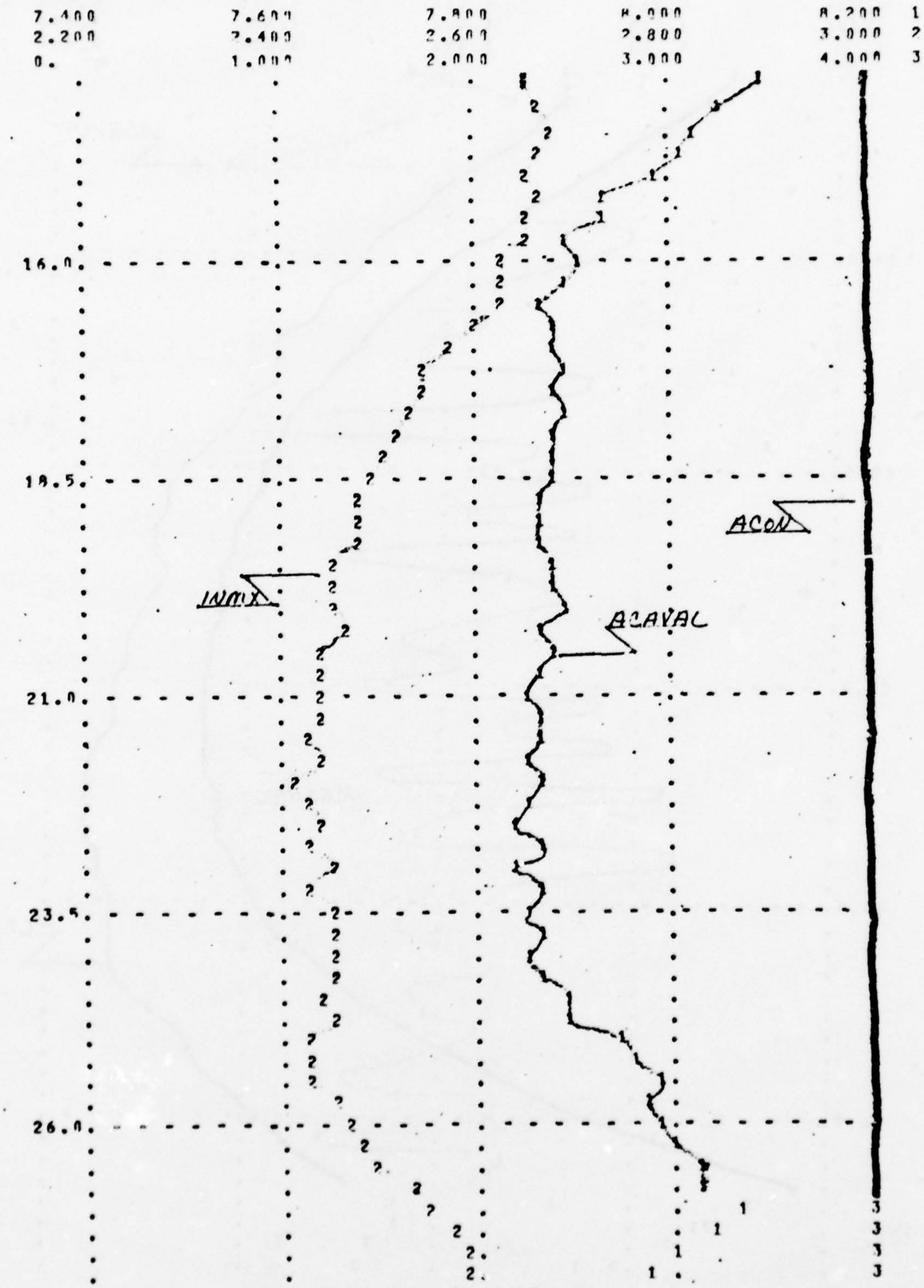

Fig. 50--Continued

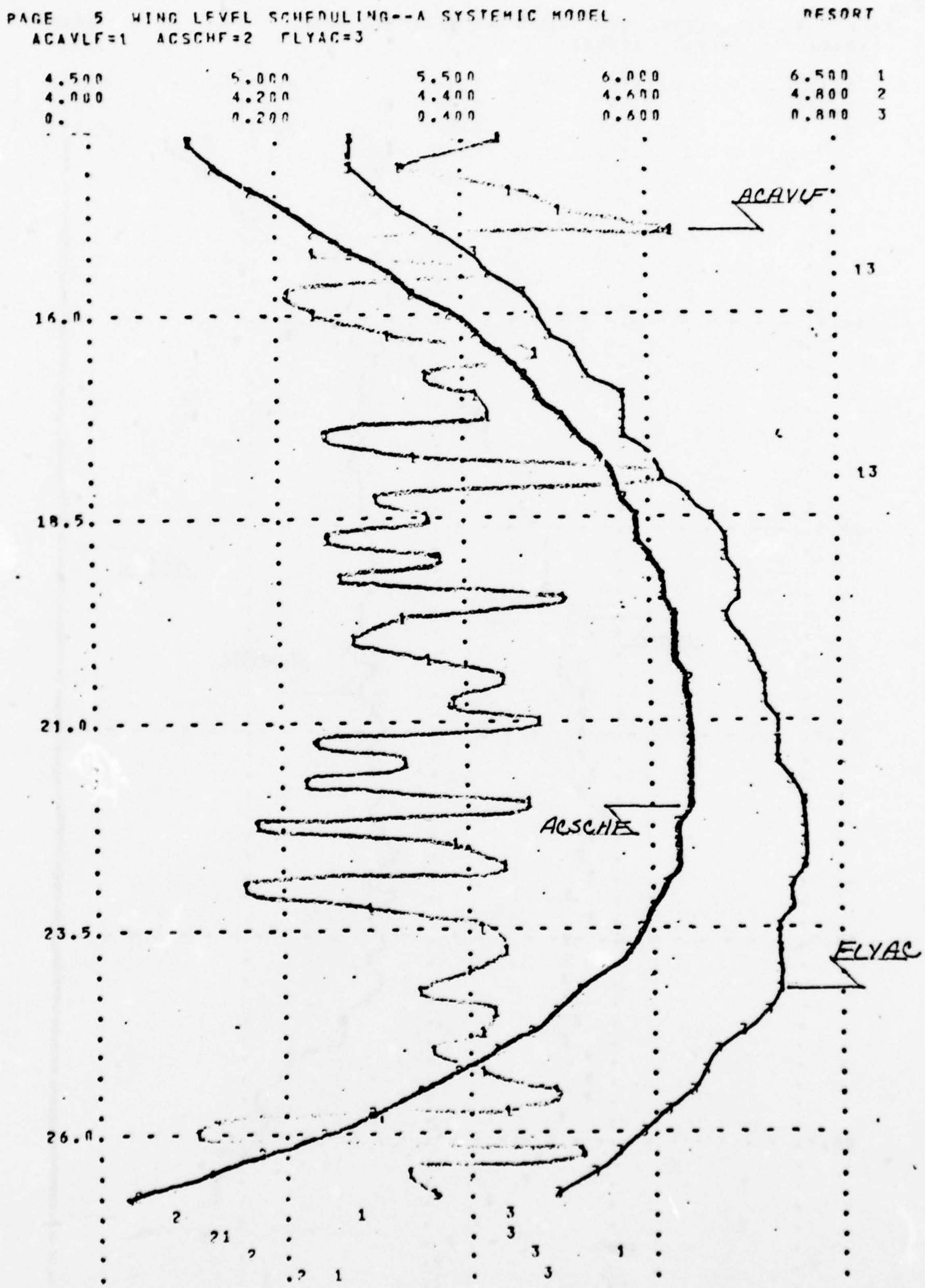

Fig. 50--Continued

FHRRMN=1 DEHRMN=2

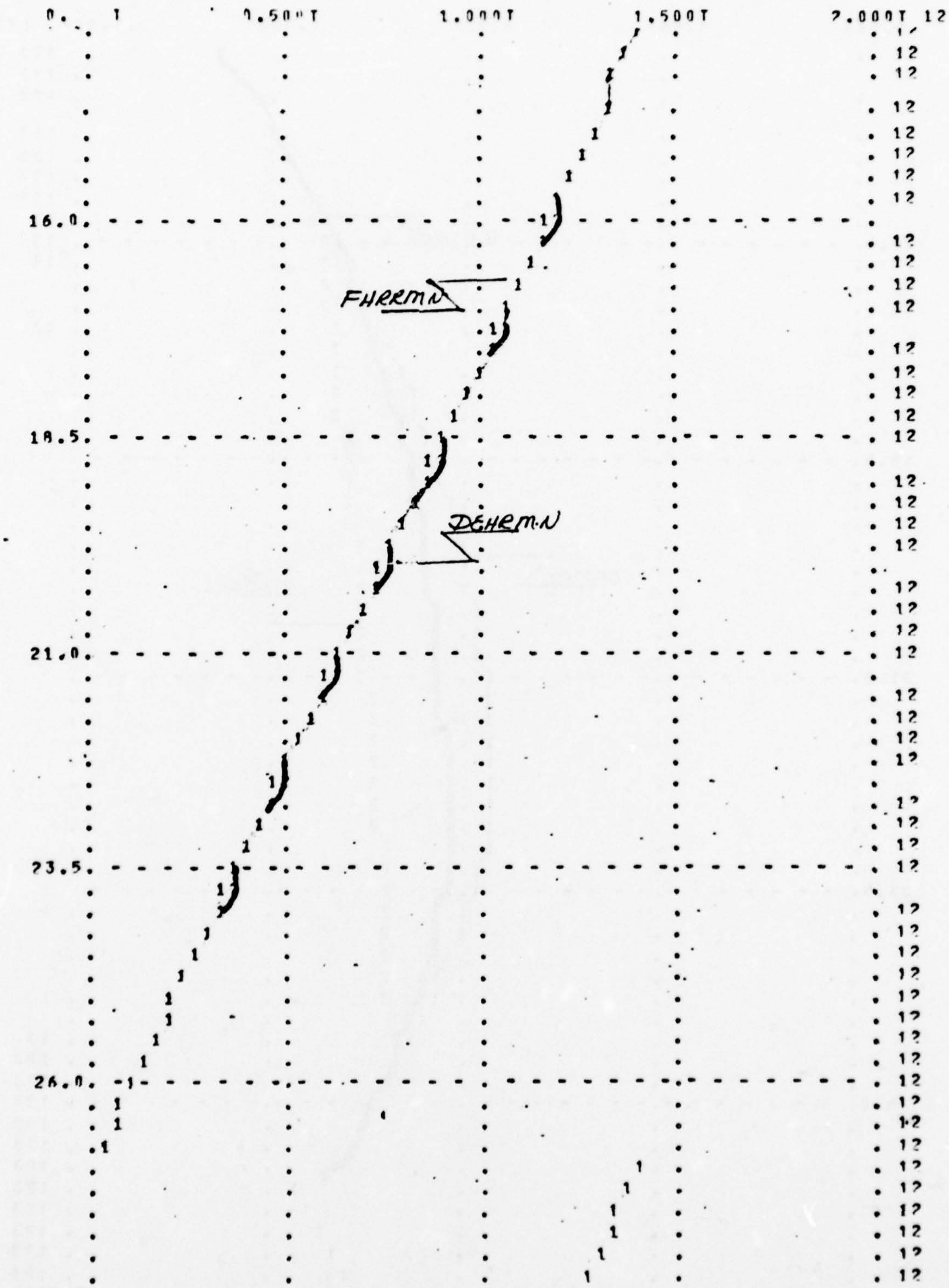

Fig. 50--Continued

PAGE 7 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESOPT
OPSORL=1 MXSORL=2 DESHRS=3

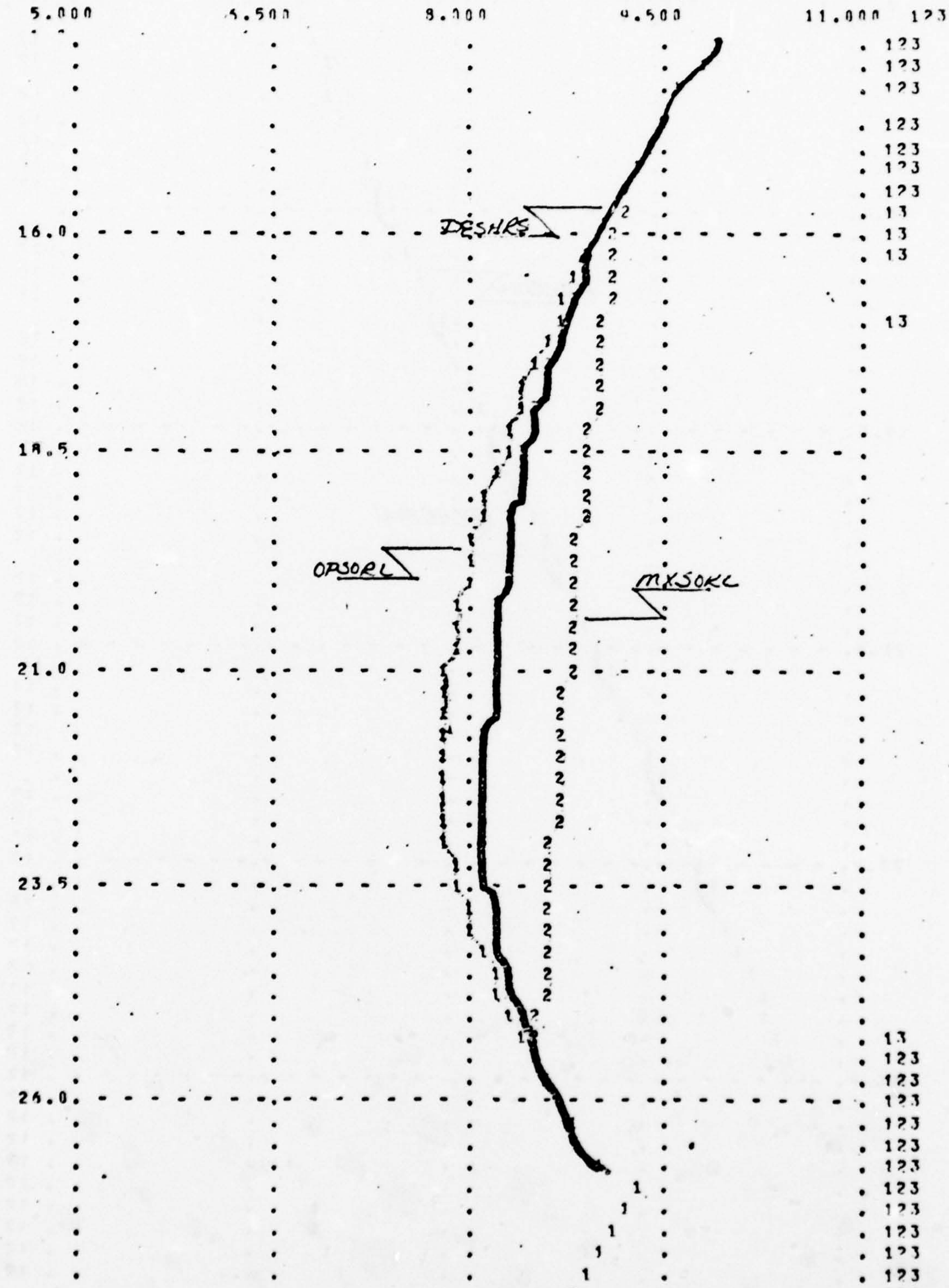

Fig. 50--Continued

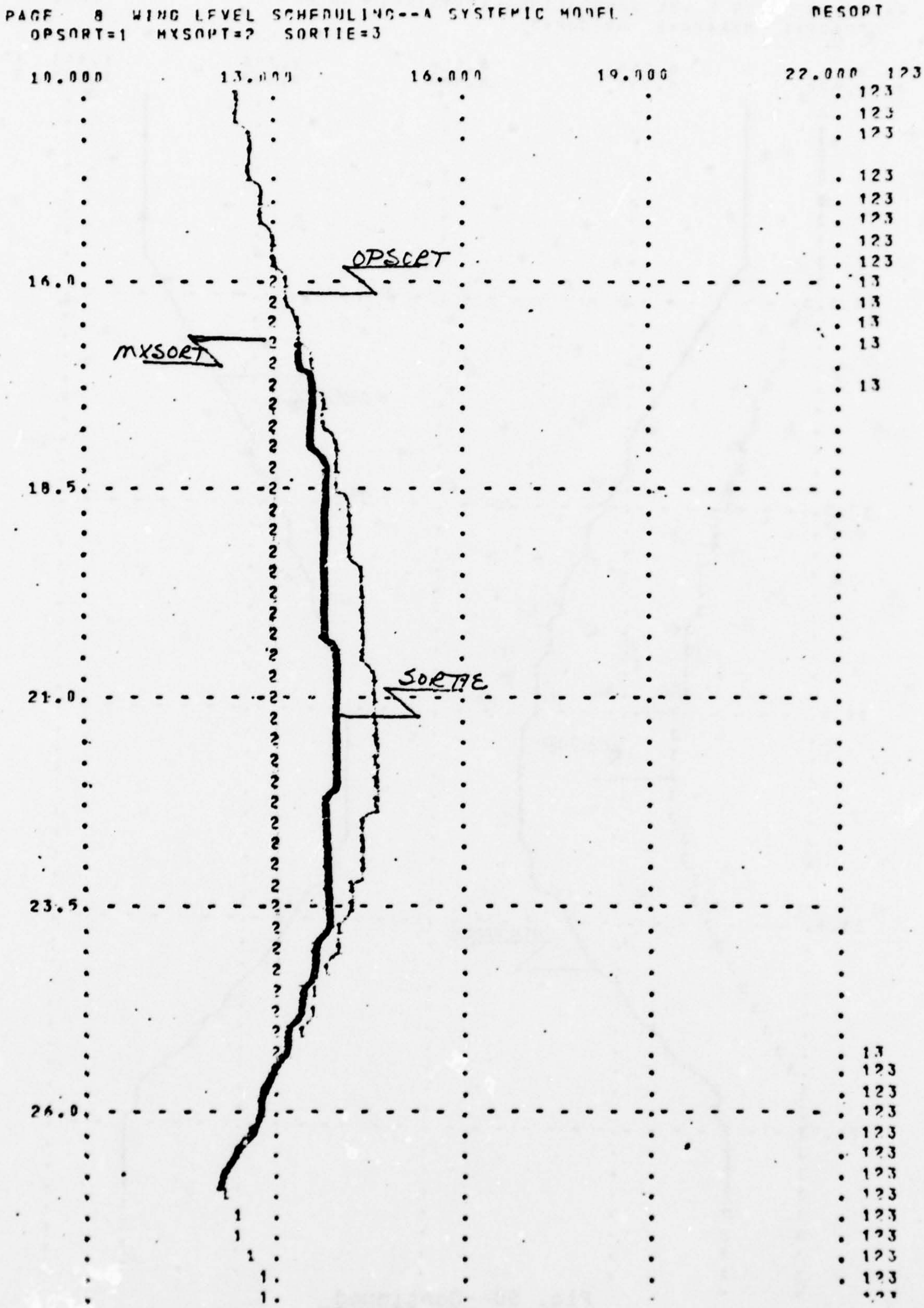

Fig. 50--Continued

PAGE 9 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESORT
OPFACR=1 MXFACR=2 UREQOP=3

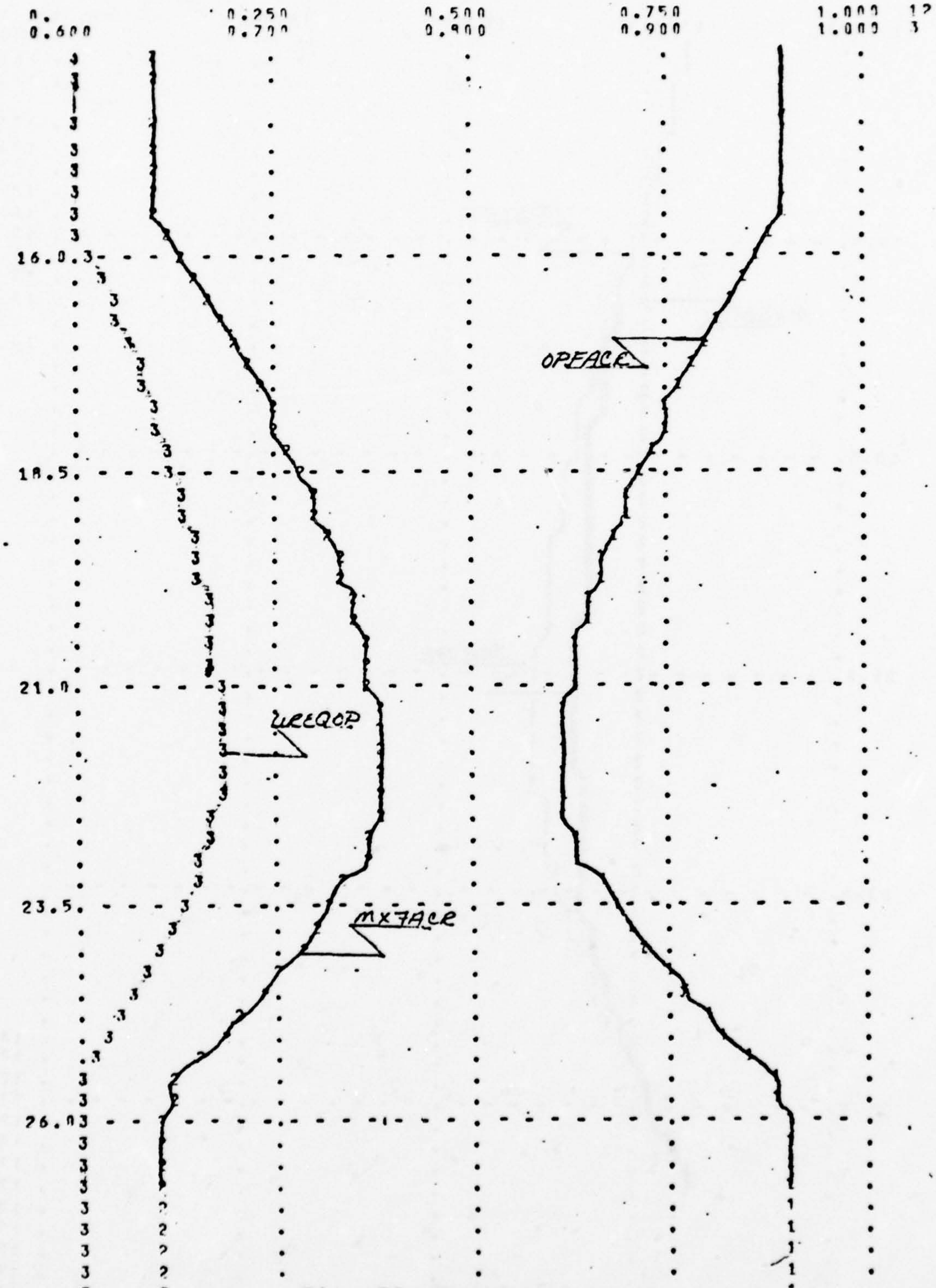

Fig. 50--Continued

PAGE 10 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESORT
SCHSPA=1 ACTMHR=2 BRKRTE=3

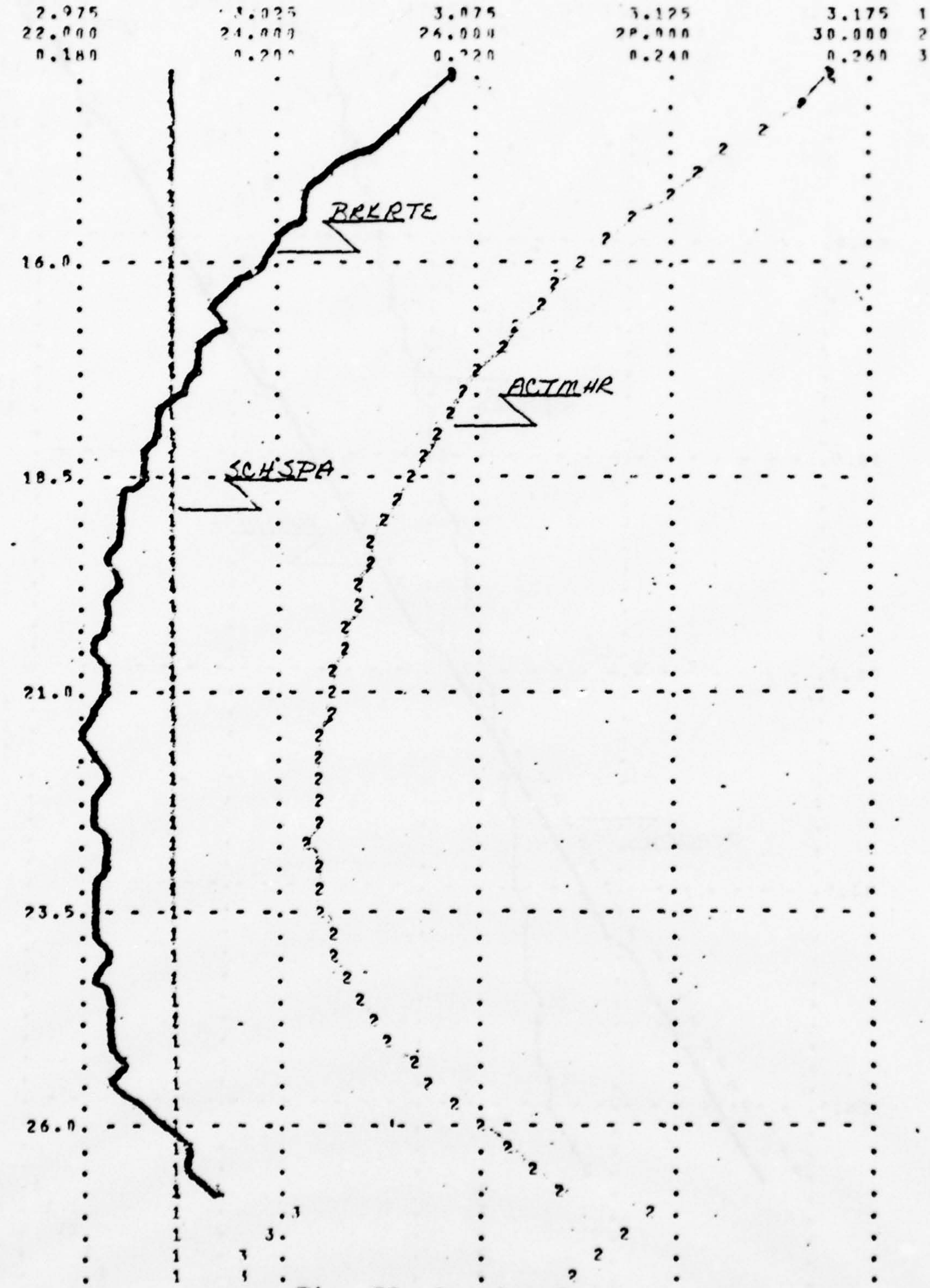

Fig. 50--Continued

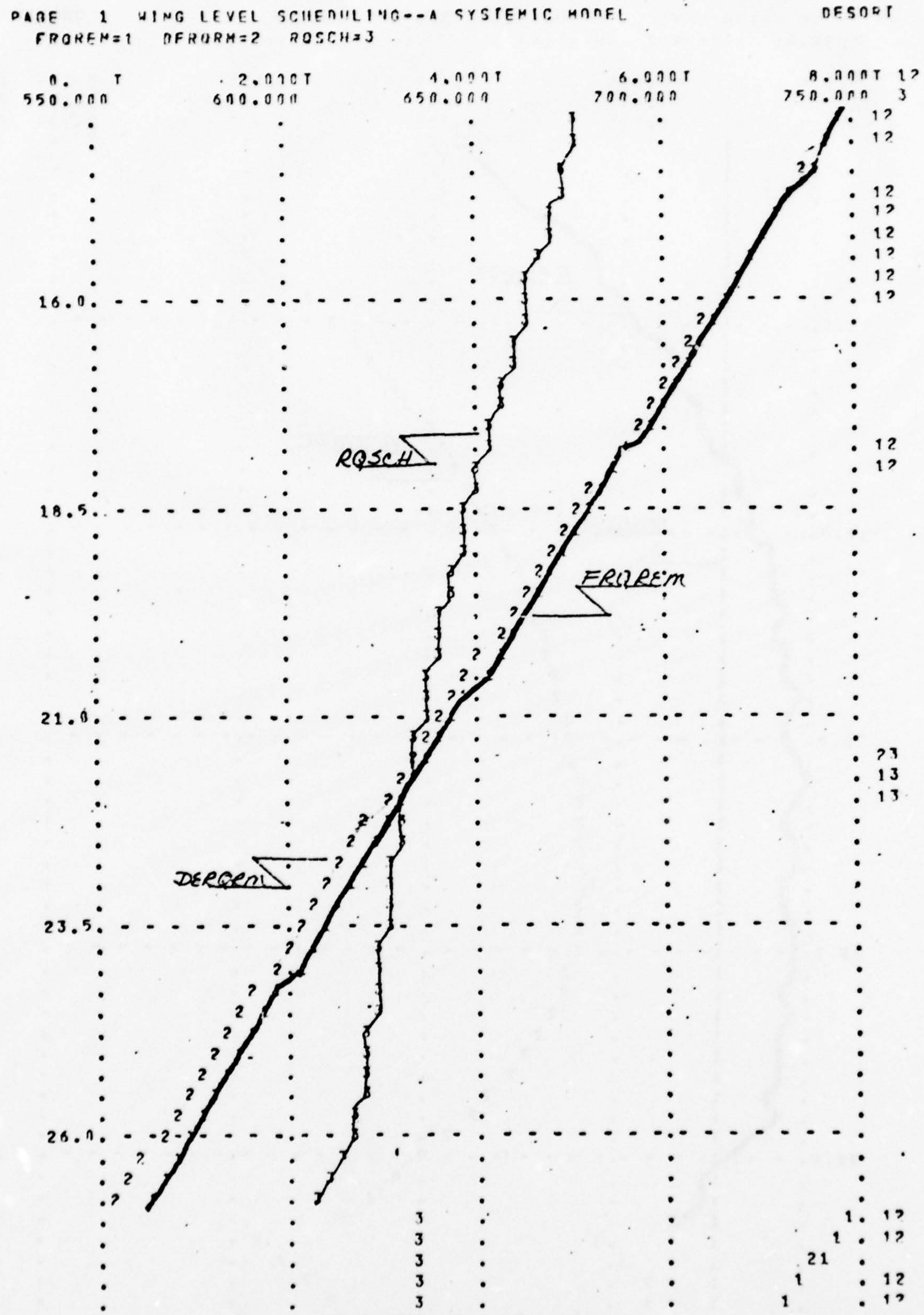

Fig. 50--Continued

PAGE 2 WING LEVEL SCHEDULING--A SYSTEMIC MODEL DESORT
RDIFFU=1 OVRBAS=2 RDIFF=3 EXRQBH=4

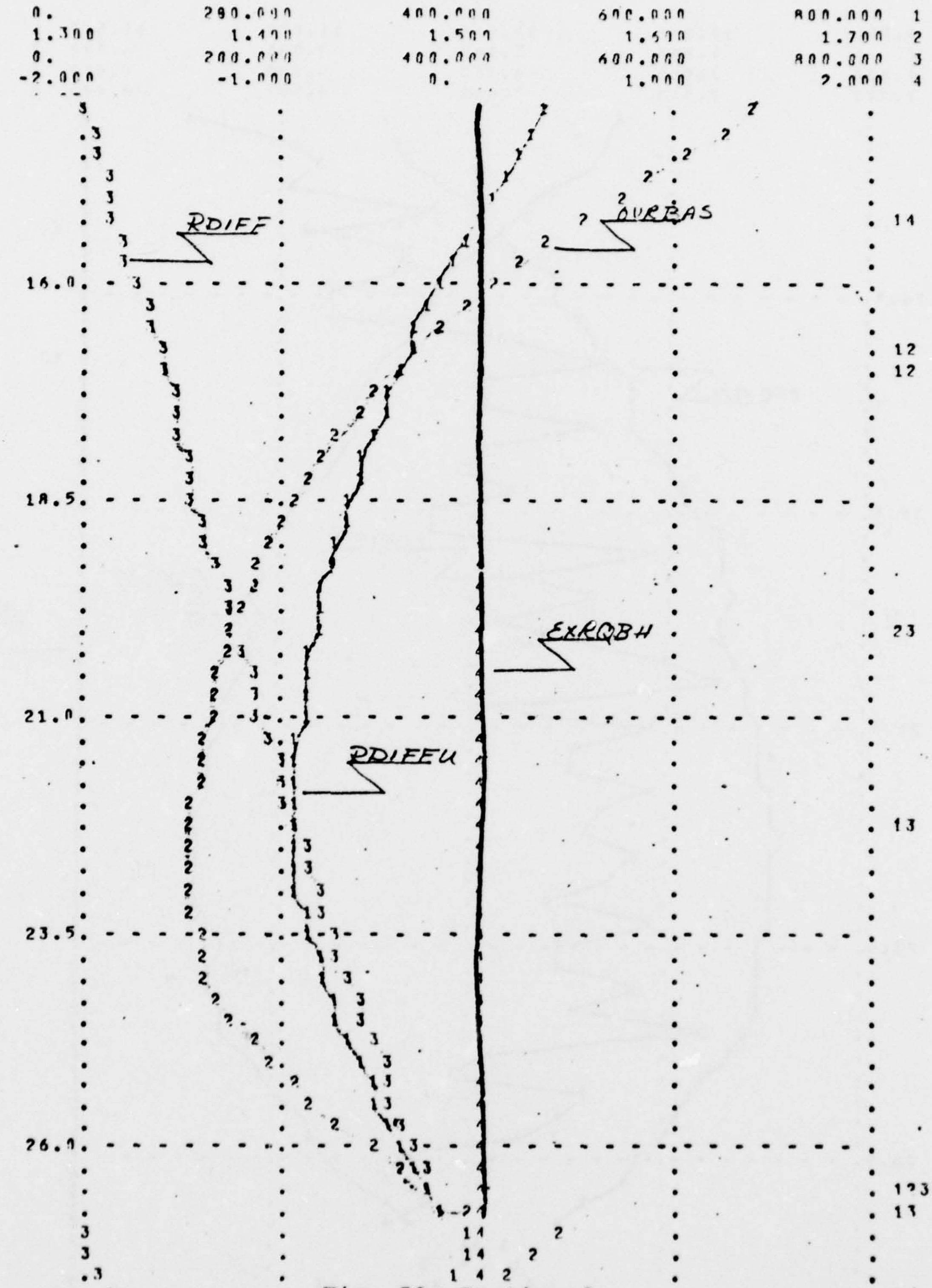

Fig. 50--Continued

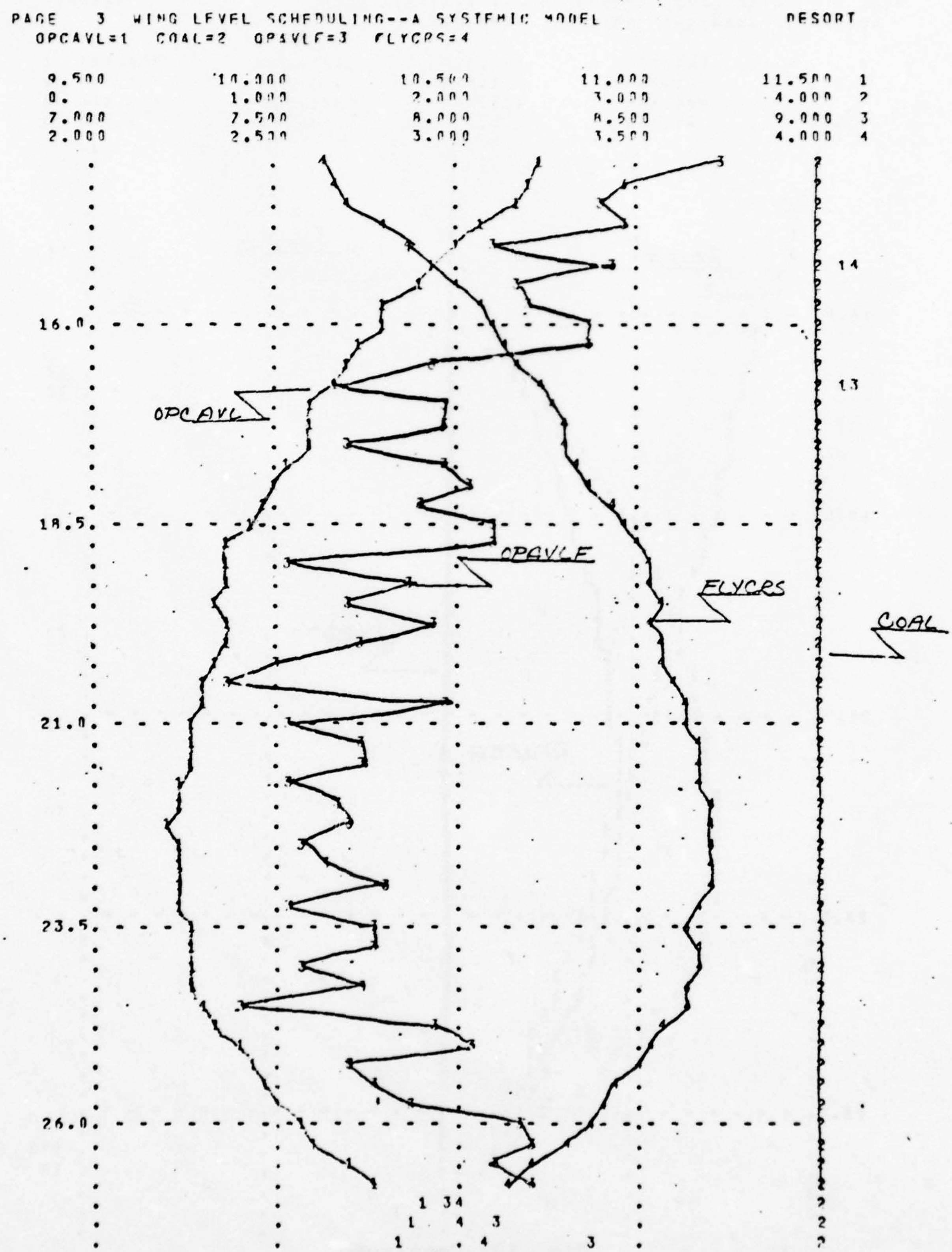

Fig. 50--Continued

increased. Other insights, however, are not as intuitive.

As was previously indicated, BRKRTE is considered, perhaps, the singly most sensitive variable in this system. BRKRTE, as shown earlier, is a function of the variables ACTSPA (actual sorties per aircraft per week), ACTMHR (total number of hours scheduled per aircraft per week), and HRSACT (total number of flying hours scheduled for the upcoming week). Again comparing Figure 50 with Appendix C, an interesting behavior pattern is observed.

In Appendix C, the following behavioral characteristics can be observed:

1. ACTMHR (the number of hours scheduled per aircraft per week) reaches its peak in mid-quarter and is concave in shape.

2. ACSCHF (the number of aircraft scheduled to fly) reaches its minimum point in mid-quarter and is therefore convex in shape.

3. SORTIE (the number of sorties scheduled per week) reaches its peak in mid-quarter and is concave in shape.

4. BRKRTE (the overall aircraft failure rate realized by the wing) is concave in shape, therefore reaching its peak in mid-quarter.

Looking at the same variables in Figure 50, however, reveals that:

1. ACTMHR reaches its minimum point in mid-quarter and is convex in shape.

2. ACSCHF reaches its maximum in mid-quarter and is therefore concave in shape.

3. SORTIE reaches its maximum in mid-quarter and is concave in shape.

4. BRKRTE reaches its minimum in mid-quarter and is therefore convex in shape.

One can begin to question the shapes of the identified plots when it is recalled that the only difference between the two systems is one, seemingly insignificant, policy difference. This policy difference, again, is to fly all available aircraft in the Appendix C system while the Figure 50 system mandates that the number of aircraft scheduled to fly (ACSCHF) will be reduced to provide a minimum of three sorties per aircraft per week. The experimental intent of the Figure 50 policy is to increase the number of spare aircraft.

Realizing, based on Equation #1100, that ACTMHR is properly responding as an inverse function of ACSCHF, the unexpected shapes of the identified plots can then be determined to revolve around the variables ACSCHF and BRKRTE. The above comparison of the two plots shows that the behavior of each variable is opposite that of the same variable in the other plot. ACSCHF, for example, reaches its peak in mid-quarter in Figure 50 while the same

variable reaches its minimum value in mid-quarter in Appendix C. This portion of the unexpected behavior can be explained by a reconsideration of the policy change.

By holding the number of sorties per aircraft per week at an artifically high level in the Figure 50 system, the total number of aircraft involved will be low if the operations scheduler desires longer sortie lengths and, hence, less sorties. A desire of longer sortie lengths in the first and last parts of the quarter is seen in both systems by observing RDIFFU (the perceived difference in flying training requirements remaining versus desired remaining as based on the scheduler's memory). RDIFFU is higher in the beginning of the quarter because the scheduler remembers that the last quarter ended with a large backlog of unaccomplished flying training requirements. Similarly, toward the end of the quarter, the scheduler begins to focus more on the actual requirement differential (RDIFF) and tends to forget past backlogs. Thus, the increasing RDIFF at the end of the quarter causes RDIFFU to increase concurrently. The larger RDIFFUs at the beginning and end of the quarter precipitate increased pressure on the operations scheduler which results in an increase in negotiated sortie length. Thus, this longer sortie results in fewer sorties at the beginning and end of the quarter. Fewer sorties, in turn, lead to fewer aircraft involved in the Figure 50 system

while less sorties per aircraft is the result in the Appendix C system. The reciprocal behaviors, therefore, can be explained. Such is not the case, however, for BRKRTE (overall aircraft failure rate).

BRKRTE, as indicated, is a function of HRSACT (total number of hours scheduled), ACTMHR (hours per aircraft per week), and ACTSPA (sorties per aircraft per week). HRSACT, as previously mentioned, is the same for both systems. The reciprocal behaviors of BRKRTE, in the two systems, is therefore a function of the relative changes in ACTSPA and ACTMHR. ACTSPA, as indicated in Chapter IV, provides the greatest amount of influence to BRKRTE in this system. ACTMHR, on the other hand, was shown to provide the least amount of influence to BRKRTE. The resultant behavior, however, still remains a function of the relative changes in the variables. The plot of ACTMHR is concave in Figure 50 and convex in Appendix C. The plot of SORTIE is concave in both systems. The plot of ACSCHF is concave in Figure 50 and convex in Appendix C. This convolution of variables of differing influence implies that BRKRTE prediction is a significantly difficult task. This highlighted level of difficulty strongly suggests that efforts be made to discover the true nature of aircraft failure rates. The counterintuitive behavior produced by a variable of this importance would surely warrant an expenditure of the necessary resources.

The final experiment conducted in this research effort was to lower the number of sorties that maintenance would willingly provide, without negotiations, from thirteen, as shown in Equation #1710, to ten. The resultant system behavior is presented in Figure 51.

The net effect imposed when making a change of this nature is to force maintenance to act with an overall, net increase in negotiating power. Hence, a comparison of Figure 51 with Appendix C should reveal a condition of longer sorties and lesser total numbers of sorties in the Figure 51 system. The rationale for the above statement is that, according to Loring AFB personnel, a lesser number of required sorties precipitates a lower total level of support required of maintenance personnel (11). Thus, lower sortie rates are more readily achievable.

Figure 51, when contrasted with Appendix C, does confirm that lower sortie rates are a result of the implemented change. One other result, however, is even more significant.

Figure 51 behavior, in total, appears significantly more stable than the behavior depicted in Appendix C. The primary reason assumed for the generated behavior is that maintenance, in the Figure 51 system, is acting to dampen oscillations in operations behavior. The result, as can be seen, is to introduce an additional smoothing effect for all attempted changes in system behavior. Total

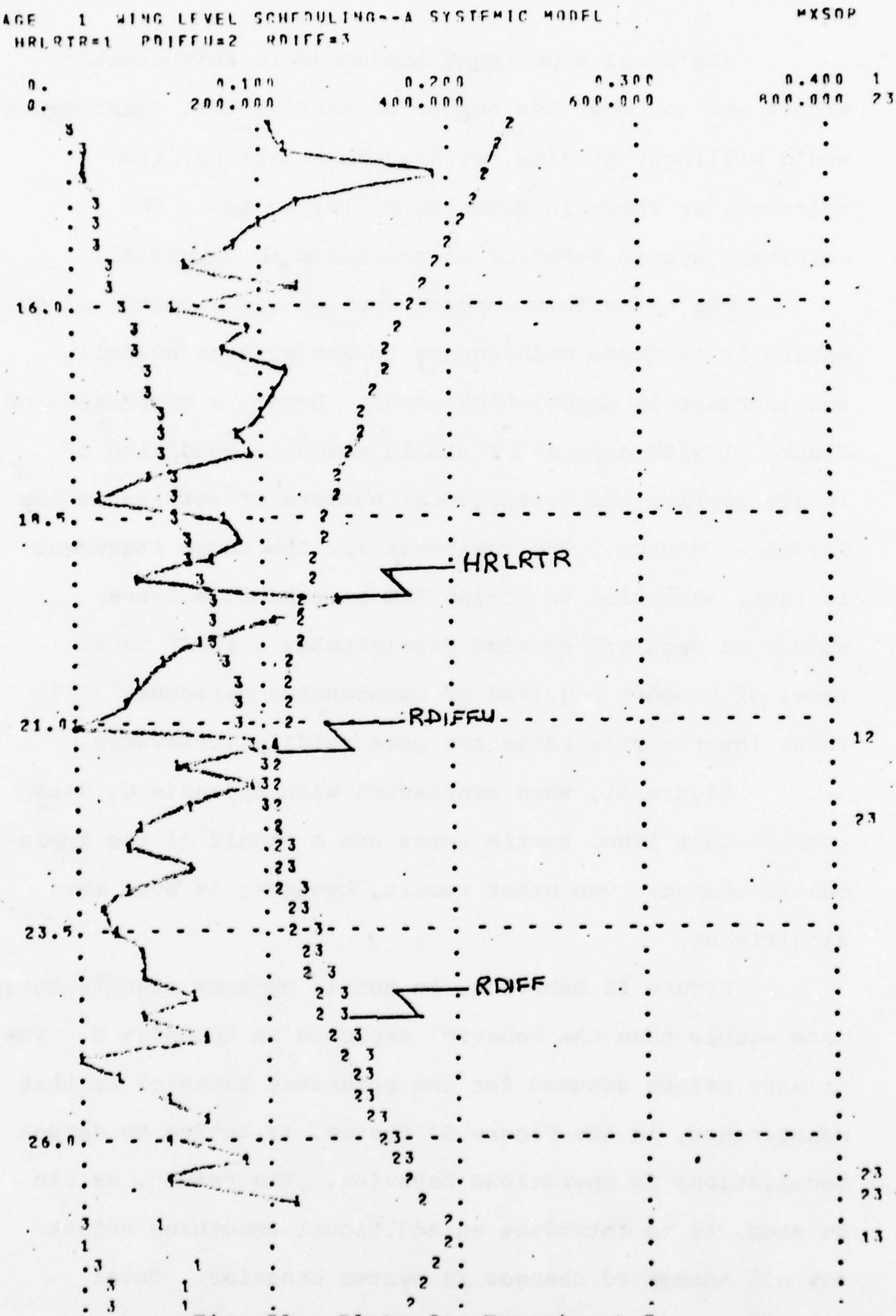

Fig. 51. Plots for Experiment 5

PAGE 2 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOR
ACTMHR=1 HRAVLF=2 HRSACT=3

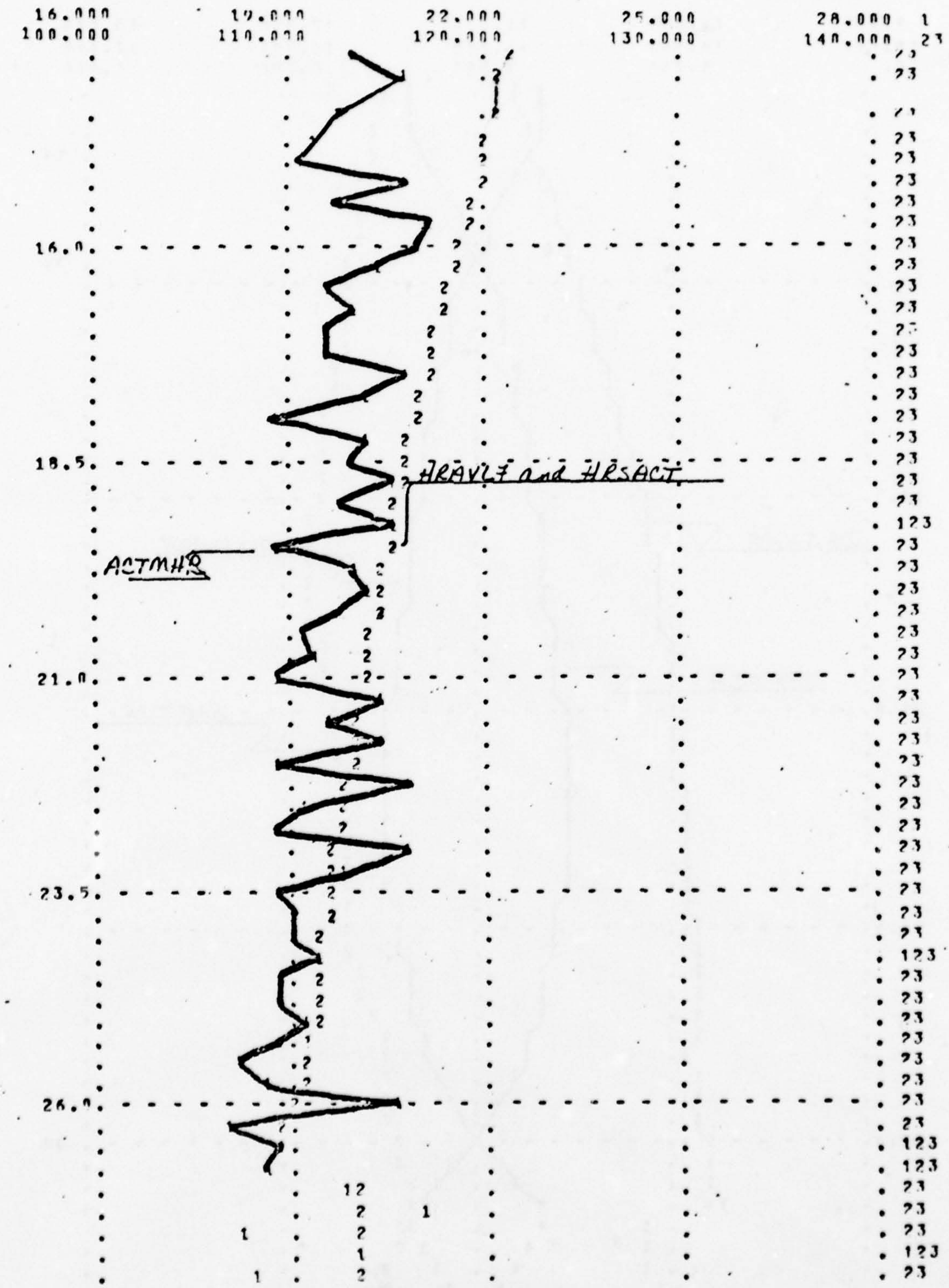

Fig. 51--Continued

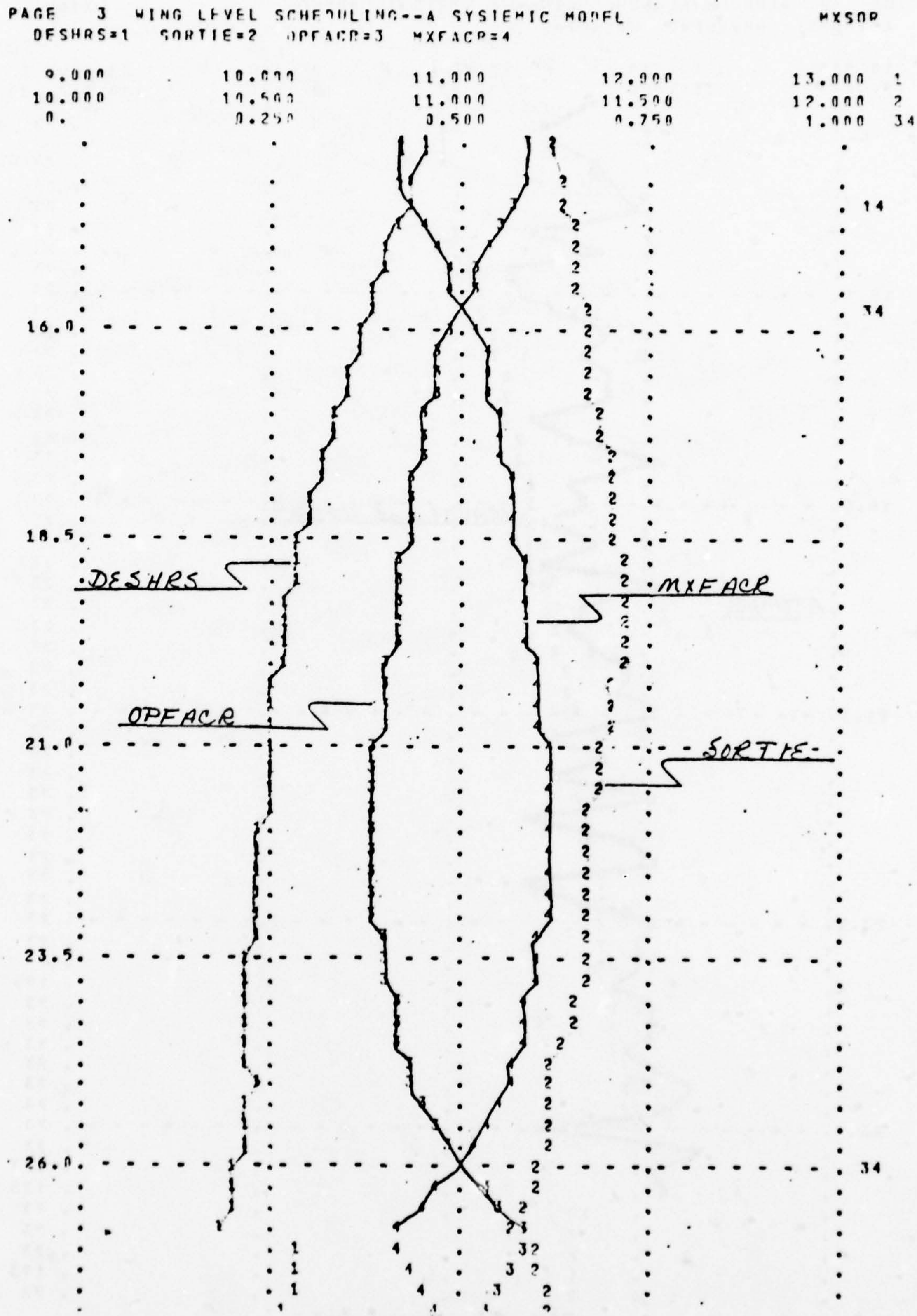

Fig. 51--Continued

PAGE 4 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOR
ACAVAL=1 INMX=2 ACON=3

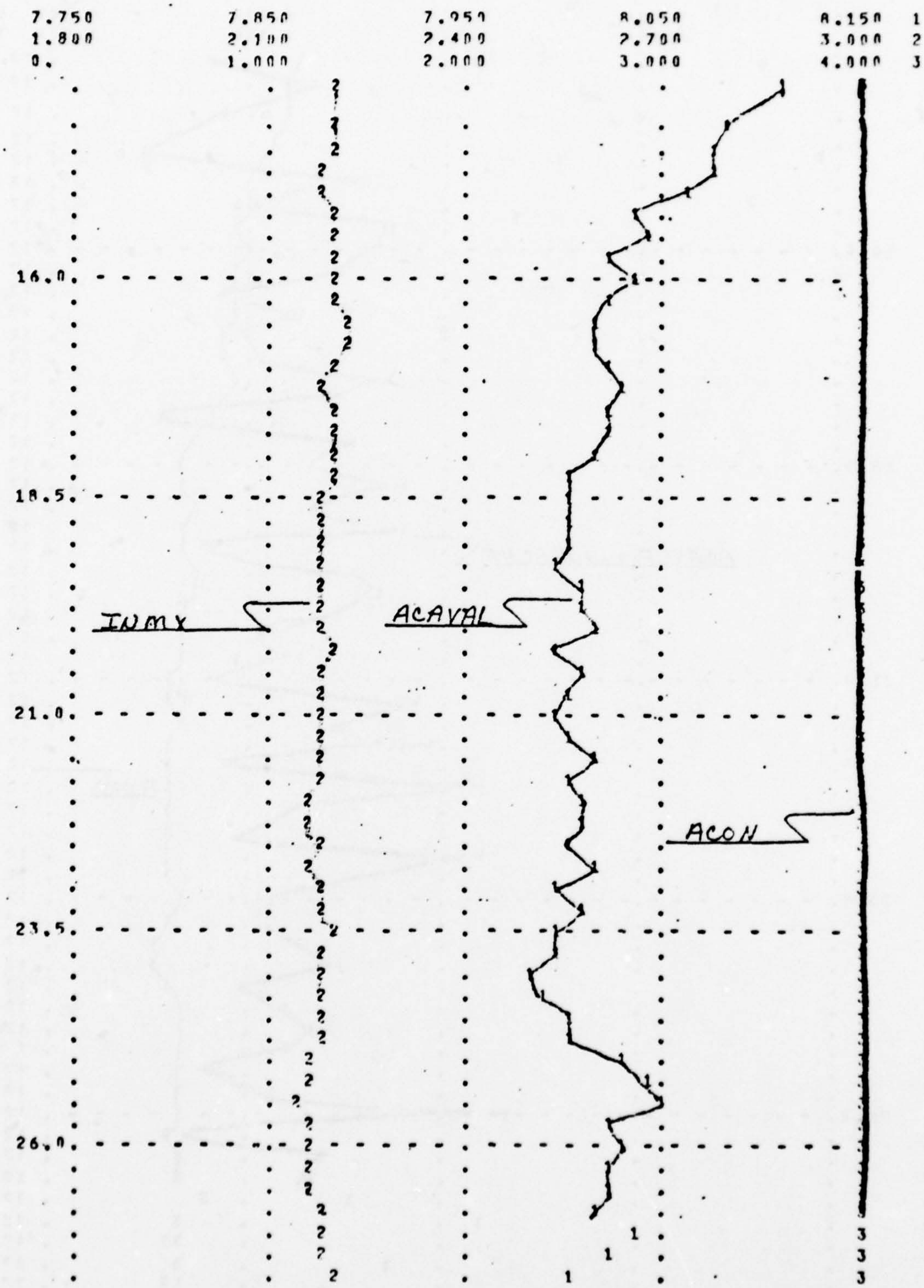

Fig. 51--<u>Continued</u>

PAGE 5 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOR
ACAVLF=1 ACSCHF=2 FLYAC=3

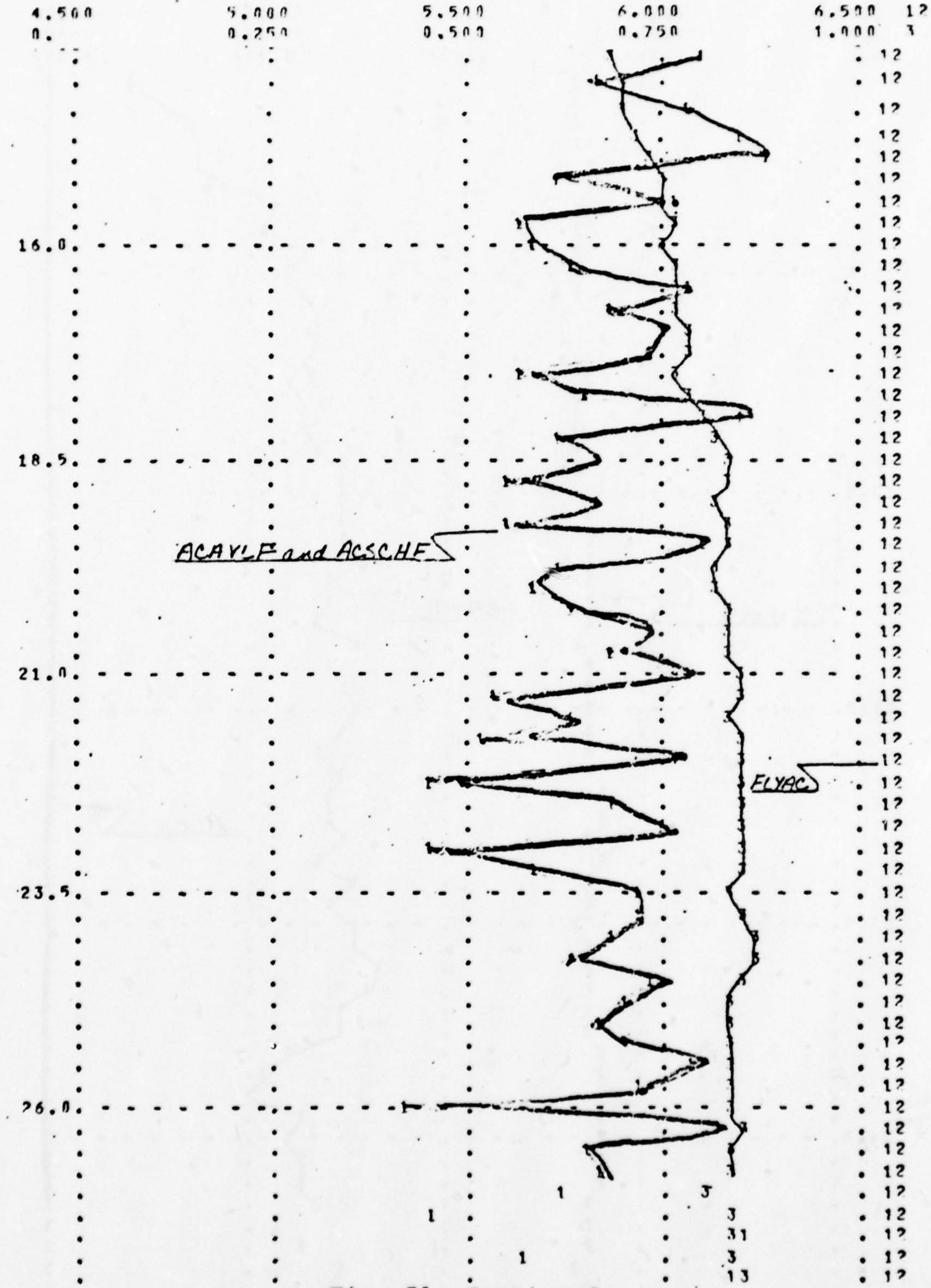

Fig. 51--Continued

PAGE 6 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOP
EHRRMN=1 DEHRMN=2

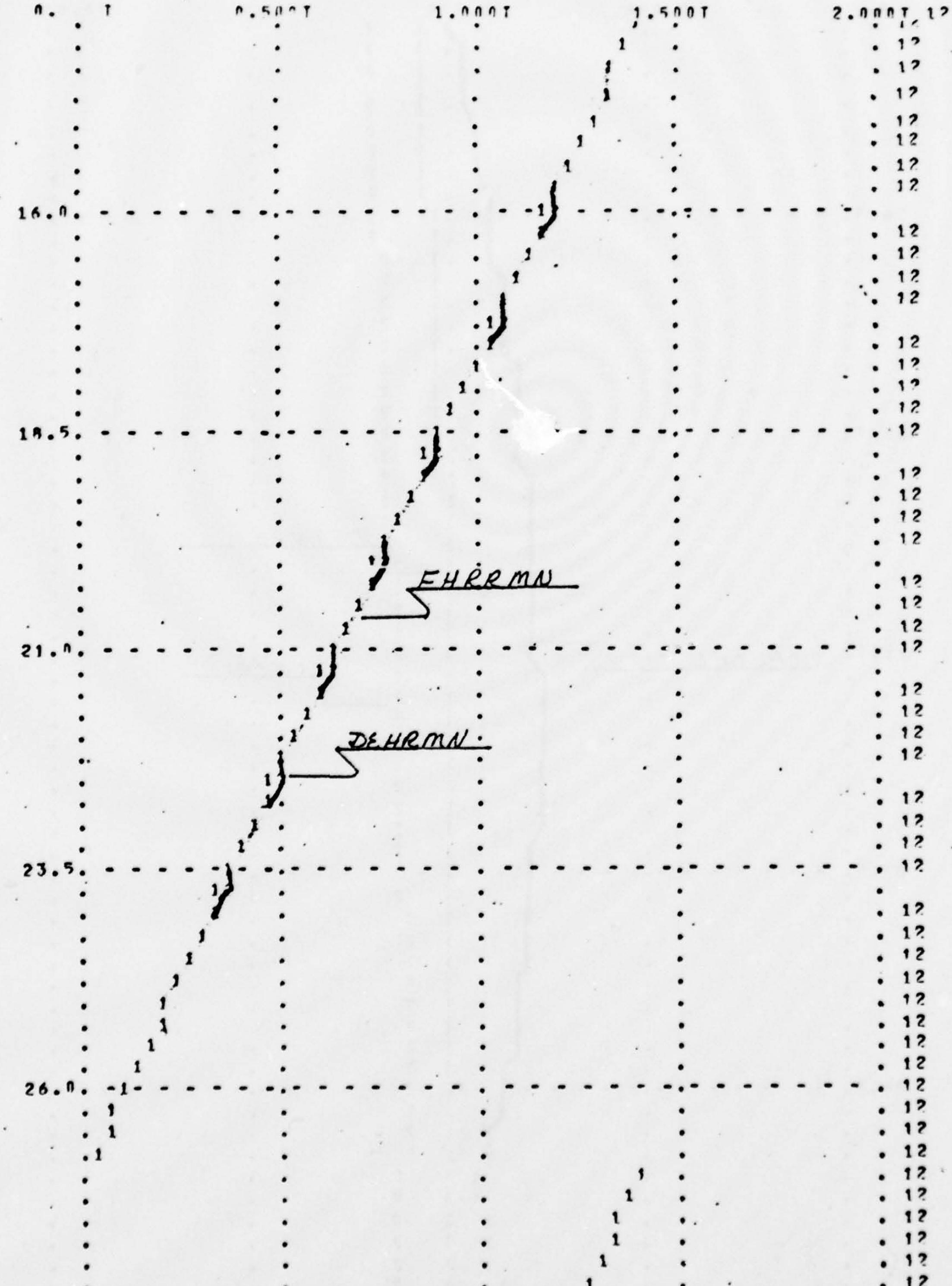

Fig. 51--Continued

PAGE 7 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOP
OPSORL=1 MXSORL=2 DESHRS=3

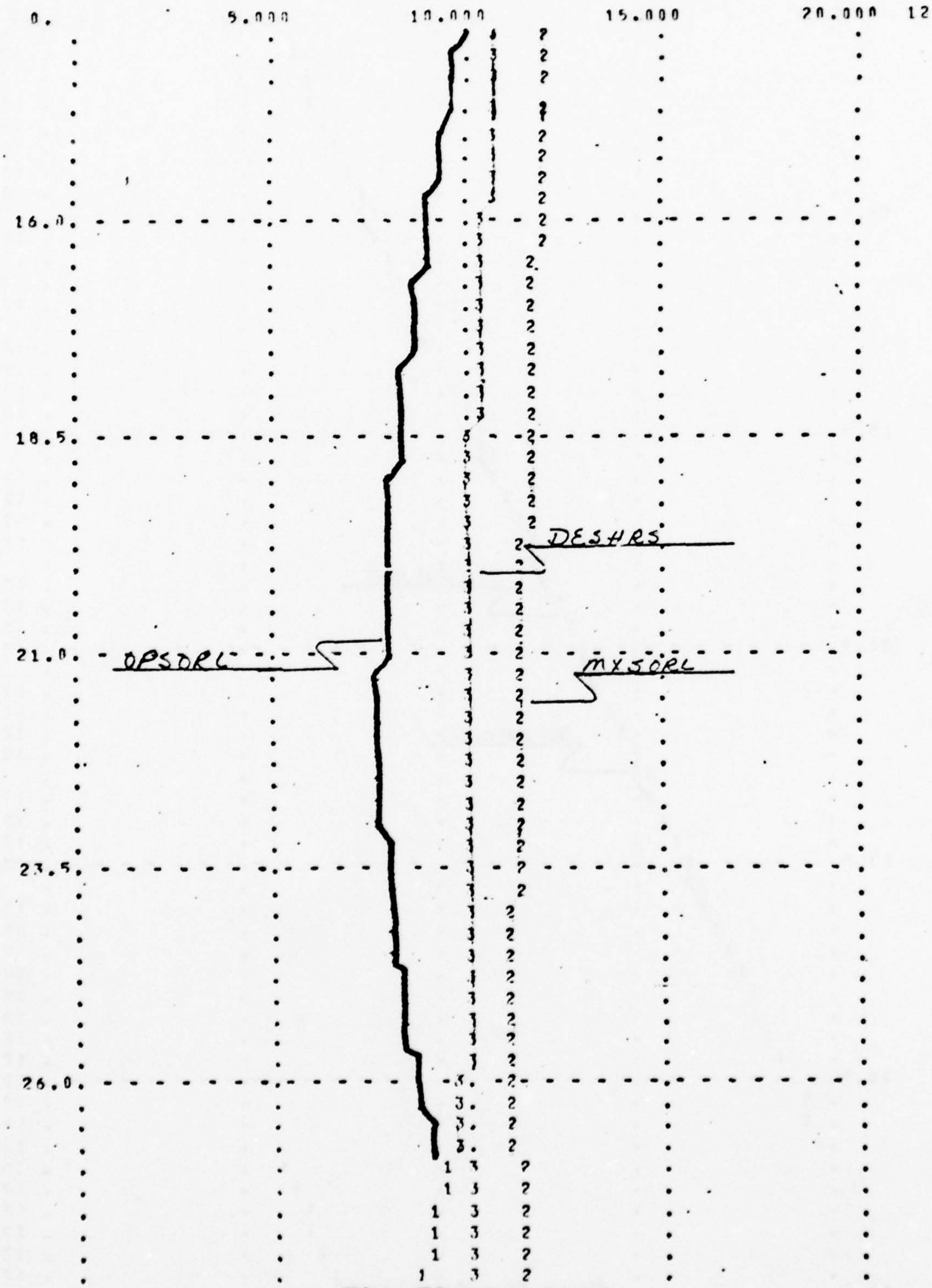

Fig. 51--Continued

PAGE 8 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOR
OPSORT=1 MXSORT=2 SORTIE=3

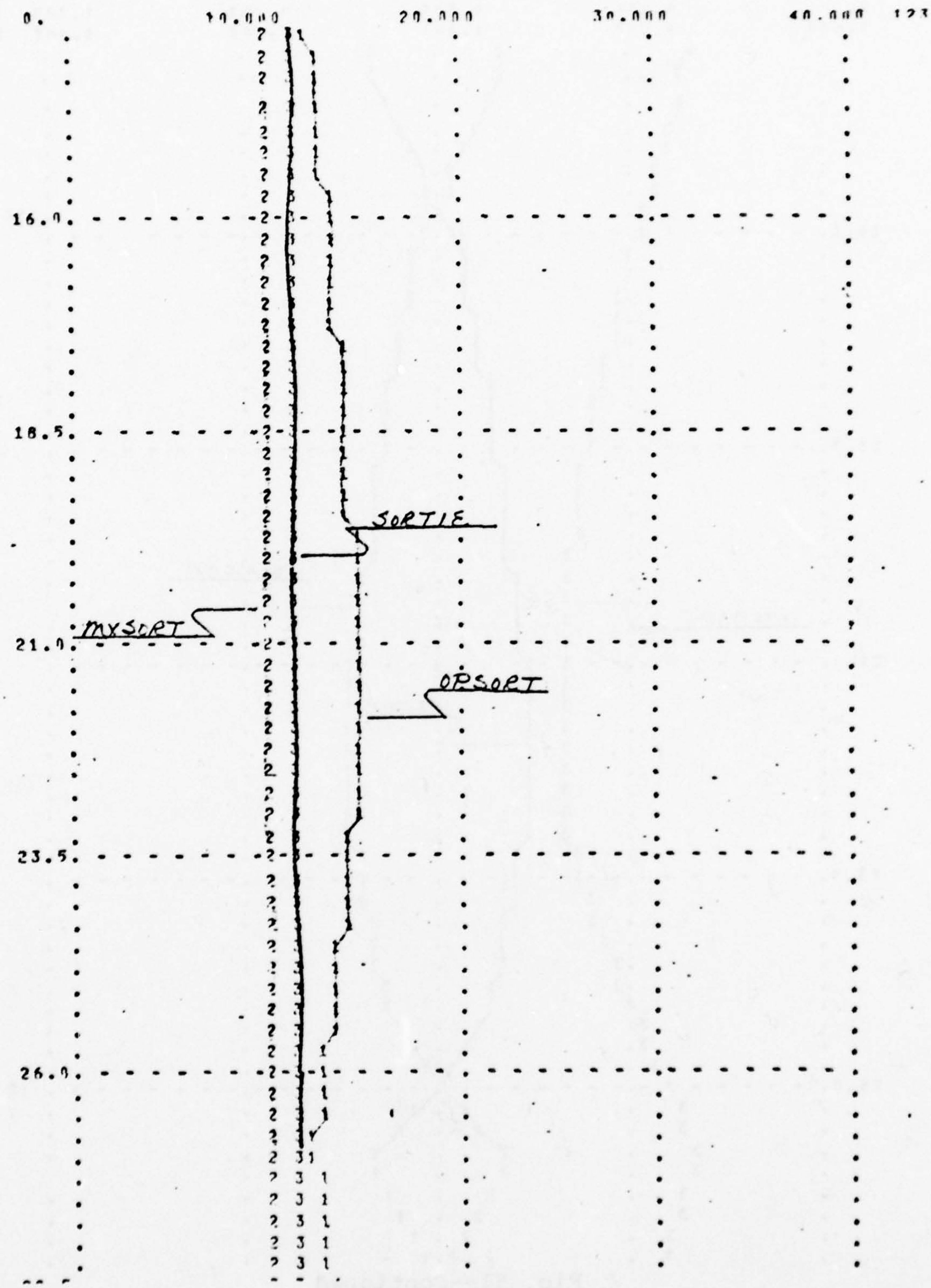

Fig. 51--Continued

PAGE 9 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOP
OPFACR=1 MXFACR=2 UREQOP=3

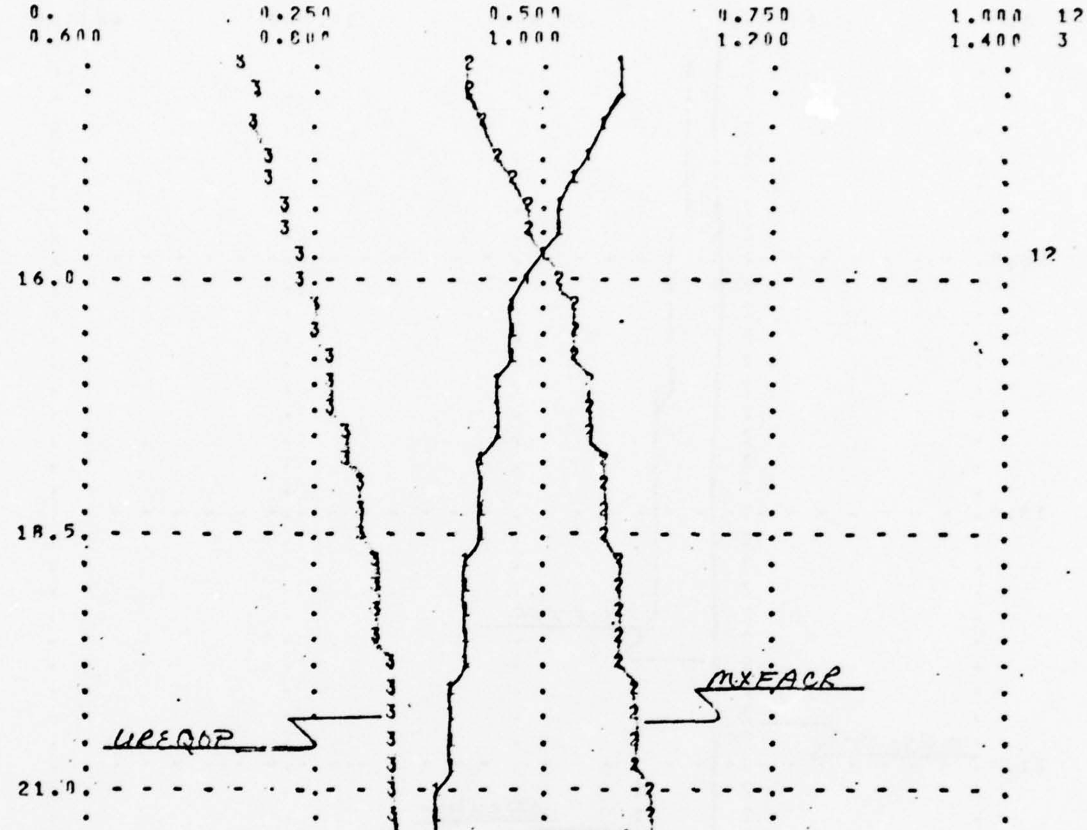

Fig. 51--Continued

PAGE 10 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOP
SCHSPA=1 ACTMHR=2 BRKRTE=3

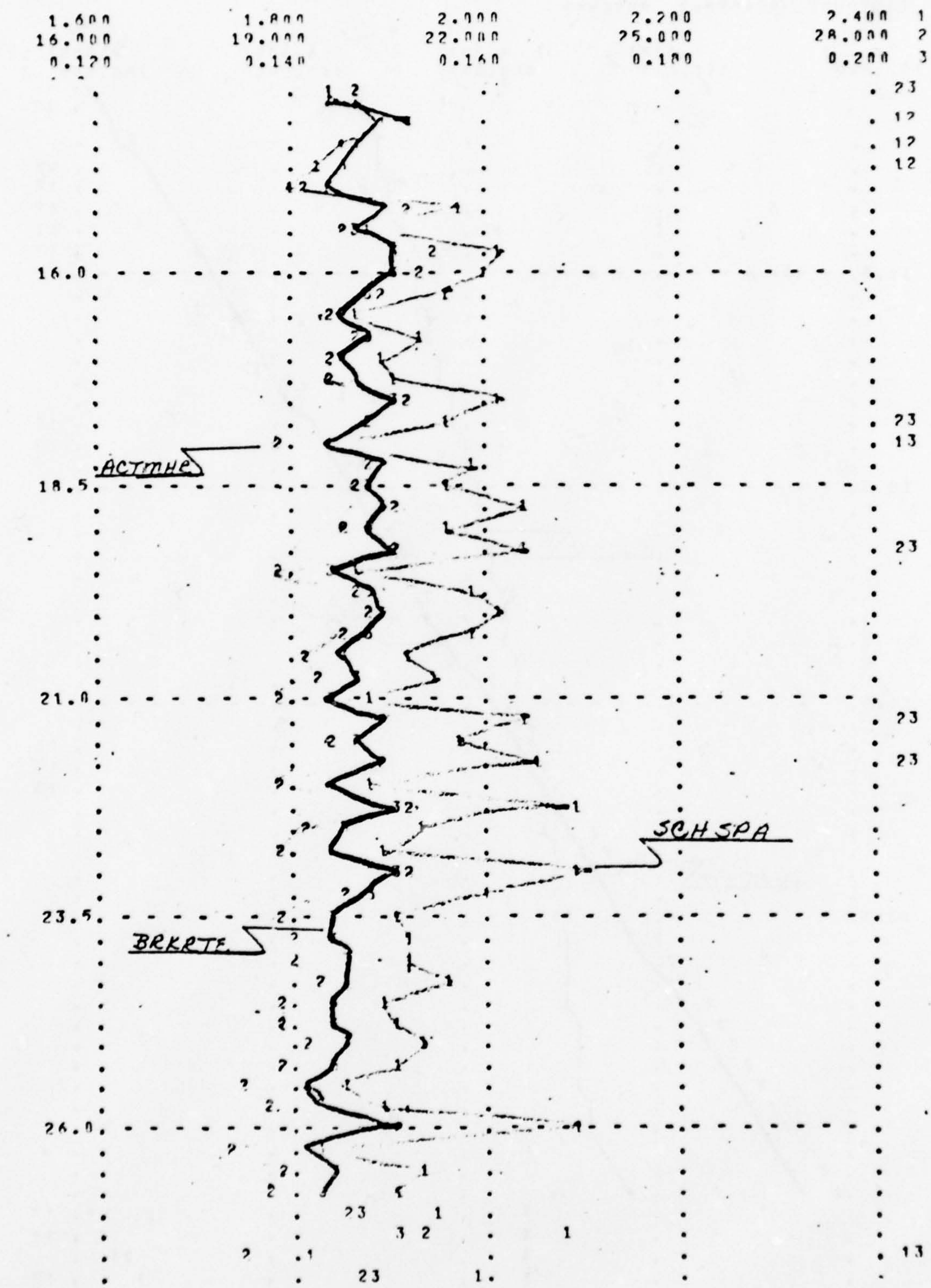

Fig. 51--Continued

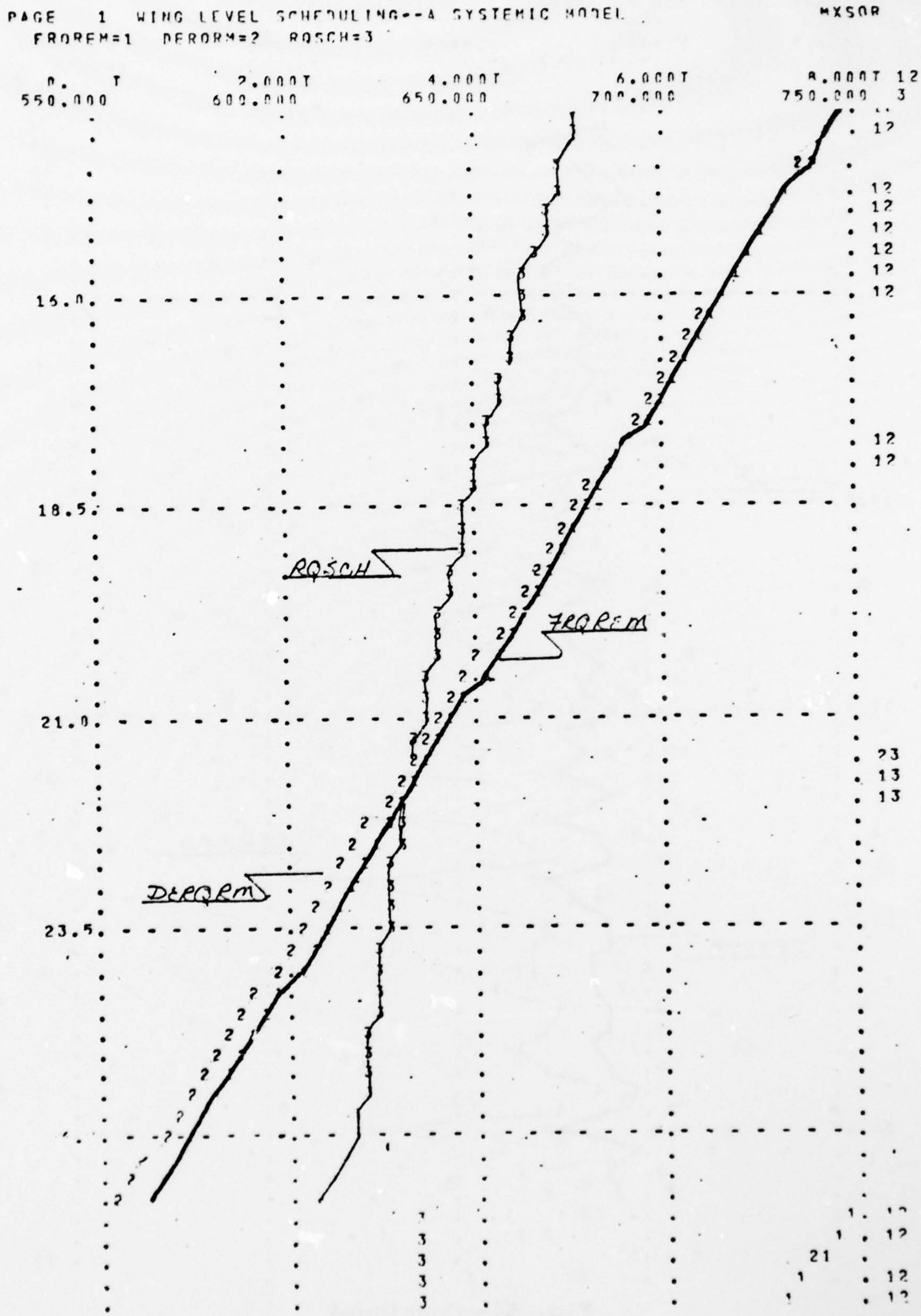

Fig. 51--Continued

PAGE 2 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOR
RDIFFU=1 OVRBAS=2 RDIFF=3 EXRQBH=4

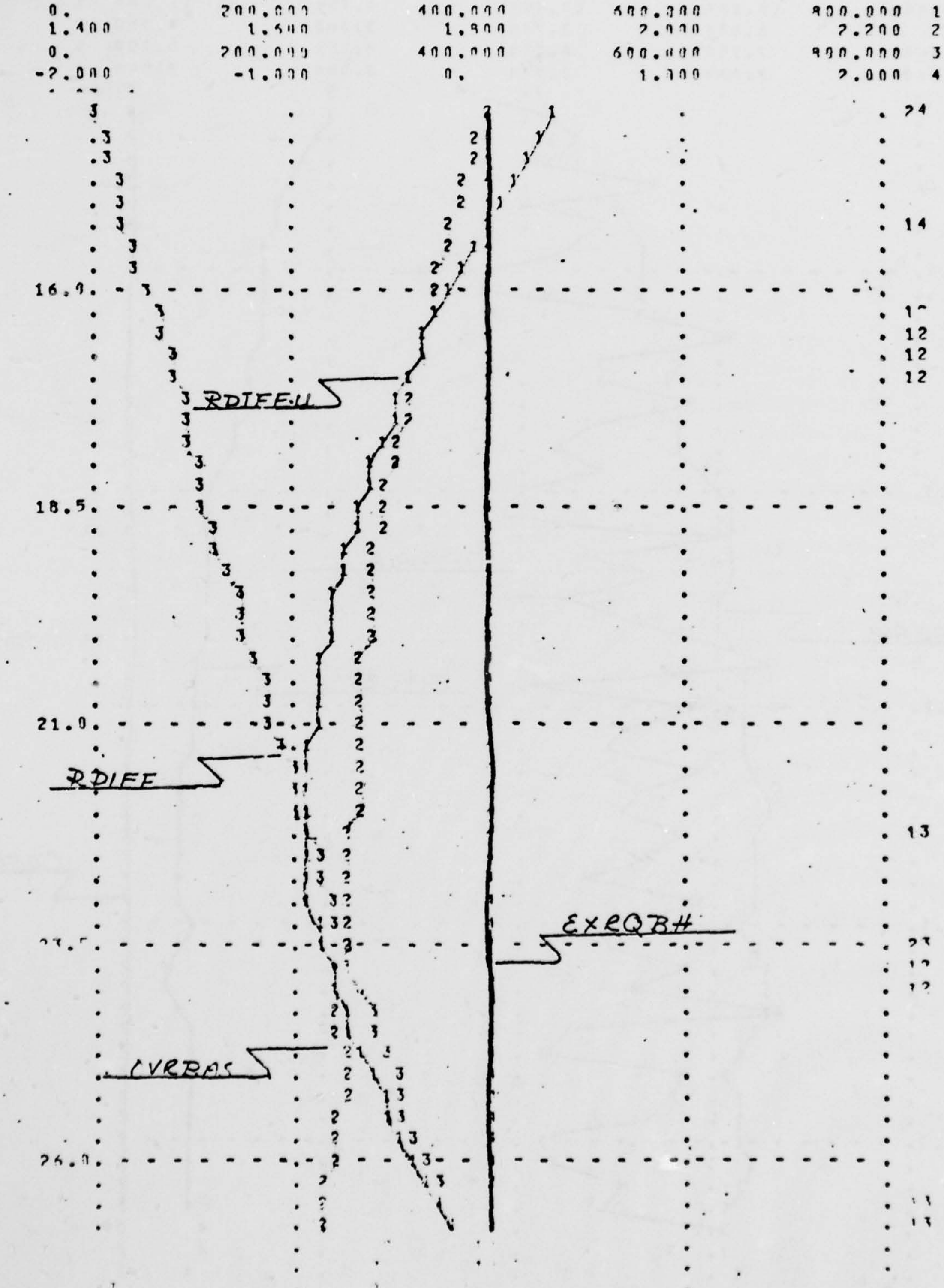

Fig. 51--Continued

PAGE 3 WING LEVEL SCHEDULING--A SYSTEMIC MODEL MXSOR
OPCAVL=1 COAL=2 OPAVLF=3 FLYCRS=4

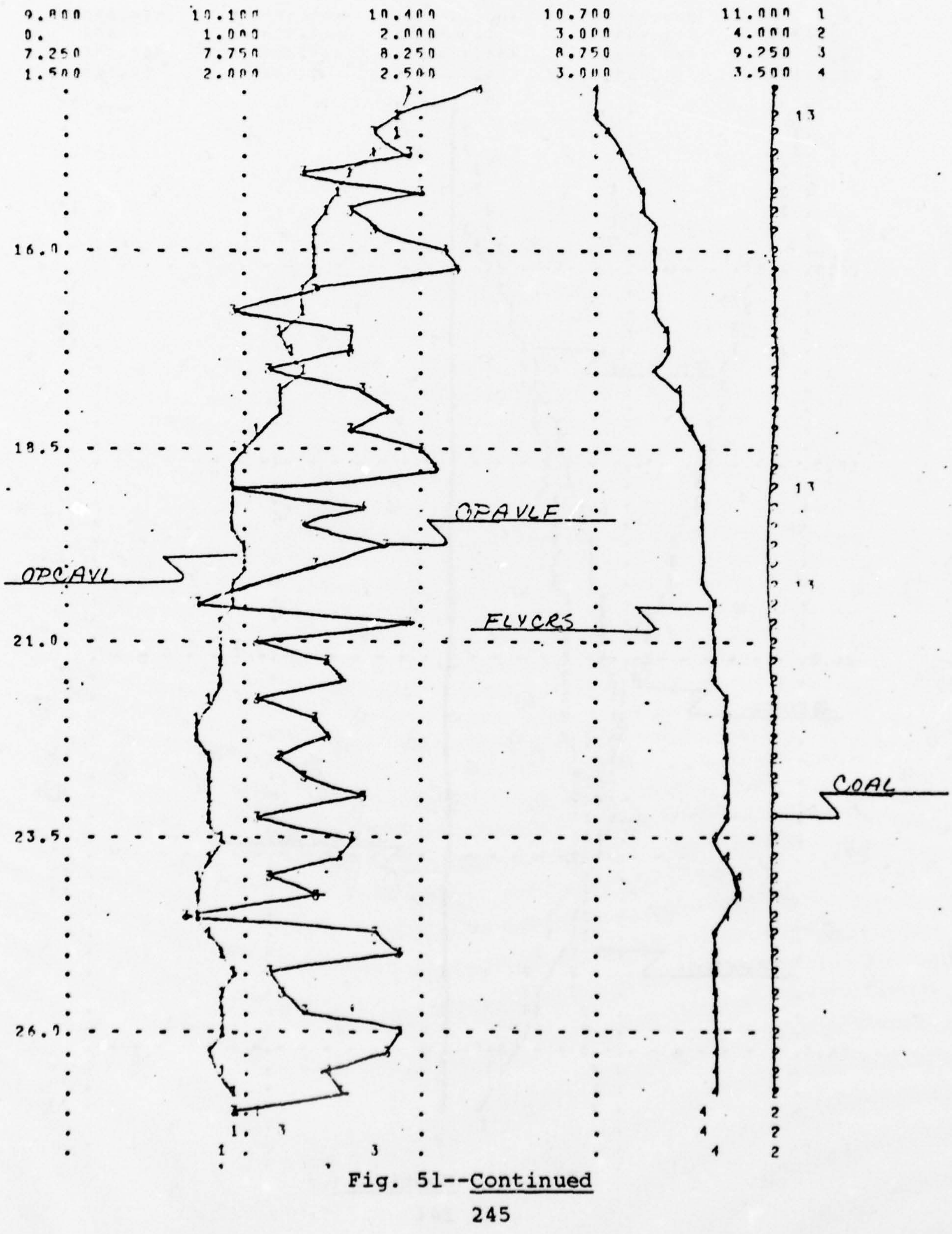

Fig. 51--Continued

control by maintenance, however, is neither implied nor purported. The effects of a change in the balance of negotiating power is simply presented for the reader's consideration.

The above report of the final experiment concludes this research effort. Chapter I provided a question for research. The following chapters detailed the search for a solution. An answer was established and presented. Validation efforts were initiated and the answer was subjected to experiment. Hence, it is now appropriate to relate the major findings and conclusions drawn from this research effort.

CHAPTER VII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Chapter I presented the opening arguments of this presentation. The problem at hand was detailed and a justification of efforts was included. A review of the literature was discussed, and the scope and limitations of this effort were presented. The research objectives were then developed. Based on these objectives, a research methodology was adopted and presented in Chapter II.

Chapter II provided a systems oriented framework upon which these efforts were based. Integrated into this chapter were thoughts and ideas applicable to the research at hand. The appropriateness of the System Dynamics methodology was conveyed. With this underlying framework constructed, a review of the objectives is now necessary to ensure that the intended task was, indeed, accomplished.

The first three research objectives were: (1) to identify the structure of the scheduling process, (2) to isolate the interaction between the factors in the scheduling system, and (3) to identify the cause-and-effect information-feedback loops that link decisions to action which results in information changes and, consequently,

new decisions. These first three objectives were addressed in Chapter III.

Chapter III directly addressed the first three research objectives. An identification of the structure of the scheduling process was presented in a causal loop format. A macro view was initially provided, thus setting the stage for further delineation. An expanded view of the causal relationships was then suggested. This expanded view provided the necessary structure, and sufficient detail, to allow the fourth and fifth objectives to be addressed.

Research objectives four and five included: (1) to formulate an acceptable description of how decisions result from available information, and (2) to construct a mathematical model which encompasses identified factors, relationships, information flows, and decision policies. The above objectives were the impetus for Chapter IV. A detailed development of all identified flows of personnel, equipment, and information led to a conceptualization of the underlying decision structure. Policy implications were apparent throughout the structure. And yet, a finalizing of the total structure surfaced additional insights. For example, the concept of the whole can only be appreciated when the whole is, indeed, viewed. Simple observation, however, does not bring out sought-after solutions. It is only after a level of understanding is

achieved so that, while the whole is seen, the process is observed and understood. The developments presented in Chapter IV did provide the necessary insights to reach the required level of understanding. As will be seen, however, levels of understanding are relative. The accomplishment of each successive objective not only enhanced understanding, but also provided a motivation to advance.

Research objectives six, seven, and eight were addressed in Chapter V. These objectives included: (1) to produce the behavior of the model through time by means of computerization, (2) to contrast model behavior with actual system behavior, and (3) to verify model validity.

Appendix C provided behavioral plots of selected variables through time. The conceptualized interrelationships were graphically depicted. Understanding was enhanced. Loring AFB was used to provide not only policy and decisional information, but also the parameter values necessary to compare system behavior with actual system behavior. The results were encouraging. While a contrast of system behavior to actual behavior is a part of the validation process, the validation effort was considered to have begun in Chapter IV. It is felt that the system structure must be sound and defendable. The relationships must be representative of the real system. Thus, if the structure was sound and the relationships real, it was

felt that the model should behave properly. This was found to be the case. With conceptual validation underway and external validation initiated, time constraints forced an advancement to objective nine.

Research objective nine prompted a chapter on system experimentation. Five experiments were conducted with the goal of increased understanding. Results of the experiments were included with the textual material to enhance reader understanding. Understanding, however, is also the topic of objective number ten.

Research objective ten prompted an effort to understand the requirements necessary for efficient scheduling. While understanding is the topic of objective ten, it is felt that understanding also provides the solution to objective ten. Understanding, in a systemic sense, has been the consistent goal throughout the whole of these efforts. Understanding seems to be the one true key that offers the increased vision as never before.

Thus, it is now possible to address the question underlying the entirety of this effort. Can the structure of the scheduling process be incorporated into a dynamic model? The effort reported in this thesis provides an affirmative answer.

Conclusions

The complexity associated with the Wing-Level Scheduling Process is significant. This complexity can be captured, however, within a systemic conceptualization and thus be transcribed into a working systemic model.

Due to the inherent complexity of the system, many behavioral patterns are both unexpected and not understood. A detailed study, however, will lead to a reduced lack of understanding.

It is a major finding of this research that the overall aircraft failure rates realized by a wing are both misunderstood and underestimated. The overall aircraft failure rate is considered to be the single-most sensitive variable in the conceptualized system. It is felt that a significant amount of energy and study will be required to understand the true nature of this elusive variable.

It is a major finding of this research effort that the relationship between levels of maintenance personnel/ utilization and sortie-generating capability is unknown.

It is a major finding of this research effort that the Wing-Level Scheduling Process can be incorporated into a dynamic model.

Recommendations

Recommendations for future research are threefold. First, and most importantly, efforts should be continued

toward the establishment of an understanding of the nature of aggregate aircraft failure rates as realized by a wing. It is recommended that a systemic approach be used in the search for the nature of this elusive variable. Second, energies should be expended toward the establishment of the relationship of maintenance personnel and utilization to sortie-generating capability. Once again, the systemic methodology is encouraged. Third, the efforts contained in this research effort should be continued and expanded. This effort appears to have developed the framework for a policy/decision level management tool. This tool can be used, in its current stage of development, to evaluate policy and decision alternatives and to highlight the ramifications of each. It was to this end that this research was devoted and it is at this end that this research was closed.

APPENDICES

APPENDIX A

VARIABLE IDENTIFICATIONS

This appendix is intended to provide, in definitional format, a working explanation of all variables used in this system. Appendix format presents variable acronym, type of DYNAMO equation associated with the variable, and variable explanation, respectively. The alphabetical ordering is intended to facilitate use.

NAME	TYPE	DEFINITION
A	C	Amplitude of cosinusoidal function.
ACAVAL	L	The number of aircraft available for scheduling at a wing.
ACAVLA	A	The number of aircraft available for alert.
ACAVLF	A	The number of aircraft available for flight.
ACFLAC	R	The number of aircraft completing flight and becoming available.
ACON	L	The number of aircraft on alert.
ACONA	R	The number of aircraft scheduled to go on alert.
ACRQMX	R	The number of aircraft requiring major maintenance (beyond normal 15-hour turn-around time).
ACSCHF	A	The number of aircraft scheduled to fly.
ACSNA	R	The number of aircraft becoming available after their scheduled flight is cancelled.
ACSNAF	R	The number of aircraft scheduled to fly that will have their flight cancelled.
ACTMHR	A	Total number of hours an aircraft is scheduled to fly in a given week.

NAME	TYPE	DEFINITION
ACTSPA	A	The actual number of sorties flown per aircraft per week.
ALLOC	A	The flying hour allocation auxiliary variable used to manipulate a varying flying hour allocation. This variable is also used to limit the maximum flying hours remaining.
ALRTAC	R	The number of aircraft completing alert tours and becoming available.
ALRTRQ	C	The number of aircraft required for alert.
BASRQS	A	The number of requirements a crew should accomplish in a six-hour sortie in order to accomplish all assigned flying training items within the quarter.
BDESHR	C	The base line sortie length used to calculate the requirements to be scheduled for all sortie lengths.
BRKRT1	A	That portion of the overall wing failure rate due to total number of hours scheduled per aircraft per week.
BRKRT2	A	That portion of the overall wing failure rate due to sorties flown per aircraft per week.
BRKRT3	A	That portion of the overall wing failure rate due to the total level of wing activity, as reflected by total number of hours scheduled.
BRKRTE	A	The actual aircraft failure rate in a given time period determined by the arithmetic average of BRKRT1, BRKRT2, and BRKRT3.
CALRAC	R	The number of crews completing combat crew rest and recouperation (CCRR) and becoming available.
COAL	L	The number of crews on alert.

NAME	TYPE	DESCRIPTION
CREWF	A	The number of crews entering flying-related activities (mission planning, flying, post mission critique).
CREWFL	R	The number of crews entering flying-related activities. (Synonymous with CREWF)
CREWN	A	The number of crews presently scheduled to fly that will ultimately be cancelled.
CREWNF	R	The number of crews presently scheduled to fly that will be cancelled. (Synonymous with CREWN)
CRFLAC	R	The number of crews completing flying-related activities and becoming available.
CRNFAC	R	The number of crews that are becoming available after their flights were cancelled.
CRSCHF	A	The actual number of crews scheduled to fly.
CRSORT	C	The desired number of sorties to schedule a crew to fly in a week.
DEACFL	A	Delay factor for flight (aircraft).
DEACNF	A	Delay factor for maintenance cancellation (4 hours after aircraft is scheduled to takeoff).
DEALRT	C	Delay factor for alert (aircraft).
DECALR	C	Delay factor for crews on alert.
DECSCF	C	Delay factor for crews in flying-related activities.
DEDNIA	C	Delay factor for crews who cannot accomplish alert or fly.
DEHRMN	A	The desired flying hours remaining in the quarter at a given period of time.

NAME	TYPE	DESCRIPTION
DEMX	C	Delay factor for aircraft in major maintenance.
DEOPNF	C	Delay factor for crews that are scheduled to fly but are subsequently cancelled.
DERQRM	A	The desired number of flying training requirements remaining in a given quarter at a given time.
DESHRS	A	A sortie length negotiated between operations and maintenance that reflects the pressures both parties are operating under.
DESORT	C	The desired number of sorties to schedule an aircraft to fly in a week.
DIFF	A	The difference between actual flying hours remaining and desired flying hours remaining.
DNA	A	The number of aircraft not scheduled for maintenance, alert, or flight (spare aircraft).
DNC	A	The number of crews on station who are physically qualified to accomplish alert and flying requirements but are not scheduled for these activities.
DNIA	L	The number of crews not available for alert. These crews may be on temporary duty, emergency leave or medically not qualified for alert.
DNIAAC	R	The number of crews that were previously not available for alert and are now becoming available.
EXCMNT	A	The factor to multiply the normal number of aircraft entering major maintenance by in order to place a larger proportion of the available aircraft into major maintenance so that the effect of a reduction in aircraft availability may be studied.

NAME	TYPE	DESCRIPTION
EXDNI	A	The factor used to end the excessive rate of crews not available for flying training.
EXDNIF	C	The factor used to increase the number of crews not available for flying training.
EXLOS	A	The factor used to end the excessive entry of aircraft into major maintenance.
EXLOSS	C	The factor used to implement the excessive entry of aircraft into major maintenance status.
EXRQBH	A	The variable used to represent the amount of flying training requirements backlog over and beyond four flying days worth of activity.
EXRQHB	A	The variable used to represent the amount of hours requested by operations in order to accomplish the flying training requirements backlog in excess of four days.
FLYAC	L	The number of aircraft currently involved in flying-related activities.
FLYALC	C	The quarterly flying hour allocation received by the wing from HHQ.
FLYCRS	L	The number of crews currently involved in flying-related activities.
FHRRMN	L	The actual number of flying hours remaining in the quarter at a given time period.
FRQMNT	C	The number of flying training requirements assigned by HHQ and the wing policy makers.
FRQREM	L	The actual number of flying training requirements remaining to be accomplished in the quarter at a given time period.
GAINWK	C	The end of a wing-directed stand down for maintenance.

NAME	TYPE	DESCRIPTION
HRAVLF	A	The number of hours that maintenance can provide based upon the assumption of flying all available aircraft and the operations request for hours.
HRGAIN	A	The factor used to end the wing-directed stand down for maintenance.
HRLOS	C	The factor used to start the wing-directed stand down for maintenance.
HRLRTC	A	The variable representing the perceived flying hour loss rate for a given time period.
HRLRTP	C	The average flying hour loss rate for the wing for one year.
HRLRTR	A	The realized flying hour loss rate for a given period of time.
HRSACT	A	The actual number of flying hours scheduled.
HRSASG	A	The actual number of flying hours assigned by HHQ.
HRSDES	A	The number of flying hours that an operations scheduler desires to schedule in order to fly out the remaining hours evenly over the remainder of the current quarter.
HRSFLN	A	The actual number of hours flown as determined by multiplying the number of sorties flown by the average sortie length.
HRSOVR	A	The actual number of hours flown which were not originally scheduled (overfly hours).
HRSPO	A	The minimum of the number of hours desired to fly out the flying hours evenly and the number of hours that maintenance is capable of providing in a given time period.

NAME	TYPE	DESCRIPTION
HRSPOS	A	The number of hours flown in a given time period determined by subtracting the number of hours scheduled and not accomplished from the number of hours scheduled and then adding the number of overfly hours flown.
HRSSNA	A	The total number of hours scheduled but not accomplished.
HRUSRT	R	The total number of hours flown in a given time period.
INMX	L	The number of aircraft in major maintenance at any point in time.
LOSWK	C	The week to start the stand down period for maintenance.
MAXHR	A	The maximum hours maintenance would provide by flying all available aircraft provided that there is no pressure to increase the number of hours due to excessive backlog in flying training requirements.
MAXHRS	A	The actual number of hours that maintenance would provide per aircraft.
MNUTIL	C	The percentage rate of maintenance manpower involved in direct maintenance. Used as a base-line for maintenance pressure.
MOPHRS	C	The maximum amount of hours a crew can be scheduled to fly in a week. This value is based upon AFR 60-1 maximum flying hours per crew per month/three month period (14).
MXFAC	A	The pressure that maintenance would be operating under should they fulfill a given sortie request from operations.
MXFACR	A	The pressure or bargaining power available to maintenance during negotiations.
MXFACT	A	The actual percentage of available aircraft that require major maintenance.

NAME	TYPE	DESCRIPTION
MXGAIN	C	The week to stop increased major maintenance.
MXGEN	A	The perceived percentage of available aircraft that require major maintenance.
MXLOSS	C	The week to start increased major maintenance.
MXSORL	A	The sortie length that maintenance would desire to schedule given the number of sorties maintenance would desire to provide to operations.
MXSORT	A	The number of sorties that maintenance desires to provide operations based upon the amount of pressure generated by the operations sortie request.
NETFAC	A	The sum of maintenance and operations pressures.
NFCREW	L	The number of operations crews that are scheduled to fly but will eventually cancel at a given point in time.
NOFLAC	L	The number of aircraft being prepared for scheduled flight that will eventually cancel at a given point in time.
OCAGTG	A	The number of crews available for ground training.
OCRASG	C	The number of crews assigned to a wing.
OPALRQ	C	The number of crews required for alert.
OPALRT	A	The number of crews available for alert.
OPAVLF	A	The number of crews available for flying training.
OPCAVL	L	The number of crews available for scheduling at a given point in time.
OPCOAL	R	The number of crews scheduled to assume alert.

NAME	TYPE	DESCRIPTION
OPDNIA	R	The number of crews becoming unavailable for alert and flying training.
OPDNIF	R	The number of crews becoming unavailable for flying training but available for alert.
OPFACR	A	The pressure or bargaining power available to operations during negotiations.
OPLIMH	A	The maximum amount of hours that operations could fly given a certain number of crews available for flying training.
OPSFAC	A	The pressure factor placed on operations due to perceived flying requirements remaining.
OPSORL	A	The sortie length desired by operations based upon perceived flying requirements backlog.
OPSORT	A	The number of sorties desired by operations based upon perceived flying requirements backlog.
OVRBAS	A	The percentage change in sortie length above or below the six-hour base sortie length.
OVRRTR	A	The actual percentage of flying hours flown that were not scheduled as related to hours scheduled.
P	C	The period for the cosinusoidal function which is equivalent to the number of weeks in a year.
PI	C	The constant π (3.14) used in the cosinusoidal function.
RDIFF	A	The difference between flying requirements remaining and desired requirements remaining at a given point in time.

NAME	TYPE	DESCRIPTION
RDIFFU	A	Perceived requirements differential based upon actual requirements differential and the scheduler's past experience in accomplishing all assigned flying training requirements within the quarter (function of the scheduler's memory).
RQASG	A	The total number of requirements assigned by HHQ and the wing staff.
RQHRBH	A	The number of flying hours required to recoup a minimum of four flying days requirements backlog.
RQMXAC	R	The number of aircraft coming out of major maintenance and becoming available for scheduling.
RQNAC	A	The number of flying training requirements scheduled but not accomplished.
RQOVR	A	The number of unscheduled flying training requirements accomplished.
RQSCH	A	The number of flying training requirements scheduled in a given time period.
RQUSRT	R	The number of flying training requirements accomplished in a given period.
RQX	A	Ramp function used to determine the desired number of flying training requirements remaining in the quarter.
RX	A	Ramp function used to determine the desired number of flying hours remaining in the quarter.
SCHACF	R	The number of aircraft entering flying-related activities.
SCHAFL	A	The number of aircraft entering flying-related activities.
SCHMEM	A	Variable used to similate a scheduler's memory that varies according to the number of weeks remaining in the quarter.

NAME	TYPE	DESCRIPTION
SCHSPA	A	The scheduled number of sorties per aircraft per week.
SORTFL	A	The number of scheduled sorties that fly.
SORTIE	A	The number of sorties scheduled.
SORTNF	A	The number of scheduled sorties that do not fly.
STADNF	C	The week to begin the excessive rate of crew nonavailability for flight.
STALOS	C	The week to begin excessive flying hour loss rate.
STPDNF	C	The week to end excessive rate of crew nonavailability.
STPLOS	C	The week to end excessive flying hour loss rate.
TIME	A	Used to represent the number of weeks since the start of simulation.
UREQOP	A	Utilization needed by maintenance to satisfy a sortie level requested by operations.
WKCLO	A	Factor to multiply flying hour loss rate by to simulate a week lost for weather or HHQ-directed stand down.
WKCLOS	A	Numerical factor used to implement weather or HHQ loss week.
WKLOS	A	Auxiliary variable used to implement weather or HHQ loss week.
WKSREM	A	The number of weeks remaining in the quarter.
X	A	Sum variable used to relate weeks remaining to time.

APPENDIX B

SYSTEM DYNAMO EQUATIONS

```
10*    WING LEVEL SCHEDULING--A SYSTEMIC MODEL
20NOTE    THIS MODEL IS BASED ON A 5 DAY WEEK
30NOTE
40NOTE    BEGIN FLY HRS RMN SECTOR
50NOTE
60N    HRSDES=133
80N    HRSFLN=80
90N    HRUSRT=80
100N    WKSREM=13
110N    HRLRTC=.12
120N    TIME=1
130N    HRSASG=0
140N    FHRRMN=1400
150C    FLYALC=1400
160A    HRSASG.K=PULSE(FLYALC,13.99,13)
170L    FHRRMN.K=MAX((CLIP((FHRRMN.J+HRSASG.J-
171X    (DT*HRUSRT.JK)),
180X    ALLOC.J,ALLOC.J,(FHRRMN.J+HRSASG.J-
181X    (DT*HRUSRT.JK)))),0)
190A    RX.K=RAMP(-107.6923077,0)
200A    DIFF.K=MAX((FHRRMN.K-DEHRMN.K),0)
210A    DEHRMN.K=(FLYALC+STEP(FLYALC,14)+STEP
220X    (FLYALC,27)+STEP(FLYALC,40))+RX.K
230A    ALLOC.K=FLYALC
240A    HRSDES.K=MAX(((FHRRMN.K/WKSREM.K)/
241X    (1-HRLRTC.K)-
250X    STEP(HRLOS,LOSWK)+STEP(HRGAIN.K,GAINWK)),0)
260C    HRLOS=0
270A    HRGAIN.K=HRLOS
280C    LOSWK=20
290C    GAINWK=21
300NOTE    LINES 202-205 REFLECT STAND DOWN
301NOTE    STAND DOWN IS USED TO AID MAINT
310A    HRLRTC.K=HRLRTP+A*COS(2*PI*(TIME.K-DT)/P)
320C    PI=3.14
330C    P=52
340C    A=.07
350C    HRLRTP=.12
360C    WKCLOS=0    FAC TO MULT HRLRTR BY
370C    STALOS=16    START INCREASED WEEKLY LOSS
380C    STPLOS=17    STOP INCREASED WEEKLY LOSS
390A    WKCLO.K=WKCLOS
400A    WKLOS.K=1+STEP(WKCLOS,STALOS)
401X    -STEP(WKCLO.K,STPLOS)
410A    WKSREM.K=X.K-(TIME.K)
420A    X.K=14+STEP(13,14)+STEP(13,27)+STEP(13,40)
430A    HRLRTR.K=MIN(((MAX((NORMRN(HRLRTC.K,.03)),
431X    0))*WKLOS.K),1)
```

```
450A    HRSSNA.K=ACSCHF.K*HRLRTR.K*ACTMHR.K
460A    OVRRTR.K=MAX((NORMRN(.Ø1,.ØØ5)),Ø)
470A    HRSOVR.K=OVRRTR.K*ACSCHF.K*ACTMHR.K
480A    HRSPOS.K=HRSACT.K-HRSSNA.K+HRSOVR.K
490A    HRSFLN.K=SORTFL.K*DESHRS.K
500R    HRUSRT.KL=HRSFLN.K
510NOTE
520NOTE    END FLY HRS REMAIN SECTOR
530NOTE
540NOTE    BEGIN AC AVAIL SECTOR
550NOTE
560NOTE    THIS MODEL ASSUMES 15 AIRCRAFT ON STATION
570NOTE
575N    HRSPO=80
580N    ACAVAL=8
590N    ACON=4
600N    ALRTAC=1
610N    INMX=3
620N    NOFLAC=Ø
630N    FLYAC=Ø
640N    ACRQMX=2
650N    ACSNAF=.5
660N    SCHACF=3
670N    MXFACT=.14
680N    MXGEN=.14
690N    BRKRT1=.1
700N    BRKRT2=.2
710N    BRKRT3=.3
720N    BRKRTE=.2
730C    ALRTRQ=4      ALERT REQUIREMENT
740C    DEMX=1
750C    DEALRT=4.6
760A    DEACFL.K=TABHL(DEACF,ACTSPA.K,Ø,15,1)
761T    DEACF=.2/.2/.4/.6/.8/1/1.2/1.4/1.6/
762X    1.8/2.Ø/2.2/2.4/2.6/2.8/3.Ø
770A    DEACNF.K=.158
780C    DESORT=1
790L    ACAVAL.K=MAX((ACAVAL.J+(DT)*(RQMXAC.JK+
791X    ALRTAC.JK+ACSNA.JK+ACFLAC.JK
800X    -ACRQMX.JK-ACONA.JK-ACSNAF.JK-SCHACF.JK)),Ø)
810L    INMX.K=INMX.J+(DT)(ACRQMX.JK-RQMXAC.JK)
820R    ACRQMX.KL=MIN((MXFACT.K*EXCMNT.K*ACAVAL.K),
821X    (ACAVAL.K-ACONA.JK))
830A    EXCMNT.K=1+STEP(EXLOSS,MXLOSS)-
831X    STEP(EXLOS.K,MXGAIN)
840A    EXLOS.K=EXLOSS
850C    EXLOSS=Ø
860C    MXLOSS=17   START WEEK FOR INCR MAINT
```

```
870C    MXGAIN=18   STOP WEEK FOR INCR MAINT
880A    MXFACT.K=MAX((MIN(MXGEN.K,.75)),.1)
890A    BRKRT1.K=TABHL(BRKR1,ACTMHR.K,2Ø,45,5)
9ØØT    BRKR1=.1/.1/.2/.3/.4/.5
910A    BRKRT2.K=TABHL(BRKR2,ACTSPA.K,1,5,1)
92ØT    BRKR2=.1/.2/.3/.45/.6
93ØA    BRKRT3.K=TABHL(BRKR3,HRSACT.K,Ø,28Ø,4Ø)
94ØT    BRKR3=Ø/.1/.1/.15/.35/.45/.5/.55
95ØA    BRKRTE.K=(BRKRT1.K+BRKRT2.K+BRKRT3.K)/3
96ØA    MXGEN.K=NORMRN(BRKRTE.K,(BRKRTE.K/6))
97ØR    RQMXAC.KL=DELAY1(ACRQMX.JK,DEMX)
98ØA    ACAVLA.K=MAX((ACAVAL.K-ACRQMX.JK),Ø)
99ØL    ACON.K=ACON.J+(DT)(ACONA.JK-ALRTAC.JK)
1ØØØR    ACONA.KL=MIN((MIN((ALRTRQ-ACON.K+ALRTAC.JK)
1ØØ1X    ,ACAVLA.K)),OPALRT.K)
1Ø1ØR    ALRTAC.KL=DELAY3(ACONA.JK,DEALRT)
1Ø2ØA    ACAVLF.K=MAX((ACAVAL.K-ACONA.JK-ACRQMX.JK)
1Ø21X    ,Ø)
1Ø3ØA    MAXHR.K=CLIP(Ø,(MIN((HRSDES.K/((ACAVLF.K)+
1Ø31X    (1E-2Ø))),45)),Ø,ACAVLF.K)
1Ø4ØA    EXRQHB.K=TABHL(EXRQH,EXRQBH.K,Ø,975,195)
1Ø5ØT    EXRQH=Ø/35/7Ø/1Ø5/14Ø/175
1Ø6ØA    MAXHRS.K=CLIP(Ø,(MIN((MAXHR.K+((EXRQHB.K/
1Ø61X    ((ACAVLF.K)+(1E-2Ø)))*2)),
1Ø7ØX    45)),Ø,ACAVLF.K)
1Ø8ØA    HRAVLF.K=MAX((ACAVLF.K*MAXHRS.K),Ø)
1Ø9ØA    HRSPO.K=MIN(HRSDES.K,HRAVLF.K)
11ØØA    ACSCHF.K=MIN((SORTIE.K/DESORT),ACAVLF.K)
111ØA    ACTMHR.K=CLIP(Ø,(HRSACT.K/((ACSCHF.K)+
1111X    (1E-2Ø))),Ø,ACSCHF.K)
112ØA    SCHSPA.K=CLIP(Ø,(SORTIE.K/((ACSCHF.K)+
1121X    (1E-2Ø))),Ø,ACSCHF.K)
113ØA    DNA.K=MAX((ACAVLF.K-ACSCHF.K),Ø)
114ØL    NOFLAC.K=MAX((NOFLAC.J+(DT)(ACSNAF.JK-
1141X    ACSNA.JK)),Ø)
115ØR    ACSNAF.KL=MAX((ACSCHF.K*HRLRTR.K),Ø)
116ØR    ACSNA.KL=DELAY3(ACSNAF.JK,DEACNF.K)
117ØL    FLYAC.K=MAX((FLYAC.J+(DT)(SCHACF.JK-
1171X    ACFLAC.JK)),Ø)
118ØA    SCHAFL.K=ACSCHF.K-ACSCHF.K*HRLRTR.K
119ØR    SCHACF.KL=SCHAFL.K
12ØØR    ACFLAC.KL=DELAY3(SCHACF.JK,DEACFL.K)
121ØNOTE
122ØNOTE   END AC AVAIL SECTOR
123ØNOTE
124ØNOTE   BEGIN OPS CREW AVAIL FOR FLY TNG SECTOR
125ØNOTE
126ØNOTE   THIS MODEL ASSUMES 2Ø CREWS ASSIGNED—
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127ØNOTE    2 CREWS ASSUMED ON LEAVE ATALL TIMES
128ØNOTE
129ØC    OCRASG=2Ø
130ØC    DEDNIA=1
131ØC    DECALR=1.5
132ØC    DECSCF=.44
133ØC    DEOPNF=.44
134ØC    EXDNIF=Ø   FAC TO MULT OPDNIF BY
135ØA    EXDNI.K=EXDNIF
136ØC    STADNF=2Ø    WEEK TO START EXCESSIVE DNIF RATE
137ØC    STPDNF=21    WEEK TO STOP EXCESSIVE DNIF RATE
138ØC    CRSORT=1   DESIRED SORTIES PER CREW PER WEEK
139ØC    MNUTIL=.6
1391NOTE    6Ø% UTIL.=13 SORTIES
14ØØNOTE    6Ø% UTIL = .1 PRESS. FACTOR
141ØN    OPCAVL=11
142ØN    DNIA=1
143ØN    COAL=4
144ØN    NFCREW=Ø
145ØN    FLYCRS=2
146ØC    MOPHRS=29.1
147ØC    OPALRQ=4
148ØN    OPDNIA=1
149ØN    CALRAC=1
15ØØN    CREWNF=Ø
151ØN    CREWFL=6
152ØL    OPCAVL.K=MAX((OPCAVL.J+(DT)(DNIAAC.JK+
1521X    CALRAC.JK+CRNFAC.JK+CRFLAC.JK-
153ØX    OPDNIA.JK-OPCOAL.JK-CREWNF.JK-CREWFL.JK)),Ø)
154ØL    DNIA.K=MAX((DNIA.J+(DT)(OPDNIA.JK-
1541X    DNIAAC.JK)),Ø)
155ØR    OPDNIA.KL=NORMRN(.Ø6,.ØØ1)*OPCAVL.K
156ØR    DNIAAC.KL=DELAY1(OPDNIA.JK,DEDNIA)
157ØL    COAL.K=MAX((COAL.J+(DT)(OPCOAL.JK-
1571X    CALRAC.JK)),Ø)
158ØA    OPALRT.K=MAX((OPCAVL.K-OPDNIA.K),Ø)
159ØR    OPCOAL.KL=MIN((MIN((OPALRQ-COAL.K+
1591X    CALRAC.JK),OPALRT.K)),ACAVLA.K)
16ØØR    CALRAC.KL=DELAY3(OPCOAL.JK,DECALR)
161ØA    OPDNIF.K=MAX((MIN(((NORMRN(.Ø5,.Ø2))*
1611X    (1+(STEP(EXDNIF,STADNF
162ØX    )-STEP(EXDNI.K,STPDNF)))),1)*
1621X    (OPALRT.K-OPCOAL.JK+CALRAC.JK)),
163ØX    Ø)
164ØA    OPAVLF.K=MAX((OPCAVL.K-OPCOAL.JK-OPDNIF.K-
1641X    OPDNIA.JK),Ø)
165ØA    OPLIMH.K=MOPHRS*OPAVLF.K
166ØA    HRSACT.K=MIN(HRSPO.K,OPLIMH.K)
```

```
167ØA    OPSORL.K=TABHL(OPSOR,RDIFFU.JK,Ø,48Ø,12Ø)
168ØT    OPSOR=6/7/8/9/1Ø
169ØA    OPSORT.K=HRSACT.K/OPSORL.K
17ØØA    MXSORT.K=TABHL(MXSOR,OPSORT.K,Ø,13,13)
171ØT    MXSOR=Ø/13
172ØA    MXSORL.K=CLIP(Ø,(HRSACT.K/((MXSORT.K)+
1721X    (1E-2Ø))),Ø,MXSORT.K)
173ØA    UREQOP.K=CLIP(Ø,((OPSORT.K/((MXSORT.K)+
1731X    (1E-2Ø)))*MNUTIL),
174ØX    Ø,MXSORT.K)
175ØA    MXFAC.K=TABHL(MXFA,UREQOP.K,Ø,.8,.1)
176ØNOTE    6Ø% UTIL =.1 PRESS. FACTOR
177ØT    MXFA=.1/.1/.1/.1/.1/.1/.1/.5/1
178ØA    OPSFAC.K=TABHL(OPSFA,RDIFFU.JK,Ø,48Ø,12Ø)
179ØNOTE    48Ø = ENTIRE CREWFORCE 4 DAYS BEHIND
18ØØT    OPSFA=.1/.3/.7/.9/1
181ØA    NETFAC.K=OPSFAC.K+MXFAC.K
182ØA    OPFACR.K=OPSFAC.K/NETFAC.K
183ØA    MXFACR.K=MXFAC.K/NETFAC.K
184ØA    DESHRS.K=(OPFACR.K*OPSORL.K)+
1841X    (MXFACR.K*MXSORL.K)
185ØA    SORTIE.K=HRSACT.K/DESHRS.K
186ØA    SORTNF.K=(HRLRTR.K*SORTIE.K)-
1861X    (OVRRTR.K*SORTIE.K)
187ØA    SORTFL.K=SORTIE.K-SORTNF.K
188ØA    ACTSPA.K=CLIP(Ø,(SORTFL.K/((SCHAFL.K)+
1881X    (1E-2Ø))),Ø,SCHAFL.K)
189ØA    DNC.K=MAX((OPAVLF.K-(SORTIE.K/CRSORT)),Ø)
19ØØA    CRSCHF.K=OPAVLF.K-DNC.K
191ØL    NFCREW.K=MAX((NFCREW.J+(DT)(CREWNF.JK-
1911X    CRNFAC.JK)),Ø)
192ØA    CREWN.K=MAX((CRSCHF.K-SORTFL.K),Ø)
193ØR    CREWNF.KL=CREWN.K
194ØR    CRNFAC.KL=MAX((DELAY3(CREWN.K,DEOPNF)),Ø)
195ØL    FLYCRS.K=MAX((FLYCRS.J+(DT)(CREWFL.JK-
1951X    CRFLAC.JK)),Ø)
196ØA    CREWF.K=CRSCHF.K-CREWN.K
197ØR    CREWFL.KL=CREWF.K
198ØR    CRFLAC.KL=DELAY3(CREWF.K,((CLIP(1,
199ØX    (SORTFL.K/((CREWF.K)+(1E-2Ø))),
1991X    Ø,CREWF.K))*DECSCF))
2ØØØA    OCAGTG.K=DNC.K+COAL.K+OPDNIF.K+(.95*DNIA.K)
2Ø1ØNOTE
2Ø2ØNOTE    END OPS CREW AVAIL FOR FLY TNG SECTOR
2Ø3ØNOTE
2Ø4ØNOTE    BEGIN FLY TRAINING REQMNTS SECTOR
2Ø5ØNOTE
2Ø6ØN    RQHRBH=Ø
```

AD-A060 449   AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC   F/G 15/3
THE WING LEVEL SCHEDULING PROCESS. A SYSTEMS APPROACH.(U)
SEP 78 L BARNIDGE, B H CIOLI
UNCLASSIFIED   AFIT-LSSR-15-78B   NL

4 OF 4
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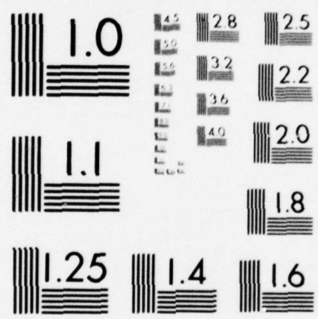

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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2070N    FRQREM=7820   REFLECTS 20 CREWS ASSIGNED
2080N    RDIFF=40
2090N    RDIFFU=40
2100A    BASRQS.K=33.5143
2110NOTE    BASRQS ARE RQMTS PER 6 HR BASE-SORTIE
2120C    BDESHR=6.0
2130C    FRQMNT=7820
2140A    RQASG.K=PULSE(FRQMNT,13.99,13)
2150L    FRQREM.K=MAX((CLIP((FRQREM.J+RQASG.J-(DT)*
2151X    (RQUSRT.JK)),
2160X    FRQMNT,FRQMNT,(FRQREM.J+RQASG.J-(DT)*
2161X    (RQUSRT.JK)))),0)
2170A    RQX.K=RAMP(((0-FRQMNT)/13),0)
2180A    DERQRM.K=(FRQMNT+STEP(FRQMNT,14)+
2190X    STEP(FRQMNT,27)+STEP(FRQMNT,40))+RQX.K
2200A    RDIFF.K=MAX((FRQREM.K-DERQRM.K),0)
2210A    SCHMEM.K=TABHL(SCHME,WKSREM.K,0,13,1)
2220T    SCHME=.02/.265/.51/.755/1/2.5/4/4.571/
2230X    5.14/5.714/6.286/6.857/7.429/8
2240R    RDIFFU.KL=SMOOTH(RDIFF.K,SCHMEM.K)
2250A    EXRQBH.K=MAX(((FRQREM.K-DERQRM.K)-480),0)
2260A    RQHRBH.K=RDIFF.JK/BASRQS.K   ACTUAL BEHIND
2270A    OVRBAS.K=DESHRS.K/BDESHR
2280A    RQSCH.K=OVRBAS.K*BASRQS.K*SORTIE.K
2290A    RQOVR.K=OVRRTR.K*RQSCH.K
2300A    RQNAC.K=(MAX((NORMRN((HRLRTC.K),.12)),
2310X    HRLRTR.K))*RQSCH.K
2320R    RQUSRT.KL=MIN(FRQREM.K,(RQSCH.K+RQOVR.K-
2321X    RQNAC.K))
2330NOTE
2340NOTE    END FLY TRAINING REQMNTS SECTOR
2350NOTE
2360PRINT    FHRRMN,WKSREM,HRSDES,HRSPO,HRSPOS,
2361X    HRLRTR,HRSSNA,
2370X    HRSOVR,HRSFLN,ACAVAL,ACRQMX,INMX,RQMXAC,ACONA,
2380X    ACON,ALRTAC,ACAVLF,DIFF,DEHRMN,MAXHR,MAXHRS,
2381X    ACTMHR,EXRQHB,
2390X    HRAVLF,DNA,ACSCHF,ACSNAF,NOFLAC,ACSNA,SCHACF,
2400X    FLYAC,ACFLAC,OPDNIA,DNIA,DNIAAC,OPCAVL,OPALRT,
2410X    OPCOAL,COAL,CALRAC,OPDNIF,OPAVLF,OPLIMH,HRSACT,
2420X    OPSORL,OPSORT,MXSORL,MXSORT,SCHSPA,ACTSPA,
2430X    DESHRS,SORTIE,SORTNF,SORTFL,DNC,CRSCHF,CREWNF,
2440X    NFCREW,CRNFAC,CREWFL,FLYCRS,CRFLAC,OCAGTG,
2450X    FRQREM,DERQRM,RDIFF,RDIFFU,RQHRBH,RQSCH,
2460X    RQOVR,RQNAC,RQUSRT,OVRBAS,EXRQBH,
2470X    UREQOP,MXFAC,OPSFAC,NETFAC,OPFACR,MXFACR,
2480X    BRKRTE,
2490PLOT    HRLRTR/RDIFFU/RDIFF
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2500PLOT    ACTMHR/HRAVLF,HRSACT
2510PLOT    DESHRS/SORTIE/OPFACR,MXFACR
2520PLOT    ACAVAL/INMX/ACON
2530PLOT    ACAVLF/ACSCHF/FLYAC
2540PLOT    FHRRMN,DEHRMN
2550PLOT    OPSORL,MXSORL,DESHRS
2560PLOT    OPSORT,MXSORT,SORTIE
2570PLOT    OPFACR,MXFACR/UREQOP
2580PLOT    SCHSPA/ACTMHR/BRKRTE
2590PLOT    FRQREM,DERQRM/RQSCH
2600PLOT    RDIFFU/OVRBAS/RDIFF/EXRQBH
2610PLOT    OPCAVL/COAL/OPAVLF/FLYCRS
2620SPEC    DT=.01/LENGTH=52/PRTPER=0/PLTPER=.25
2630RUN   BASIC
```

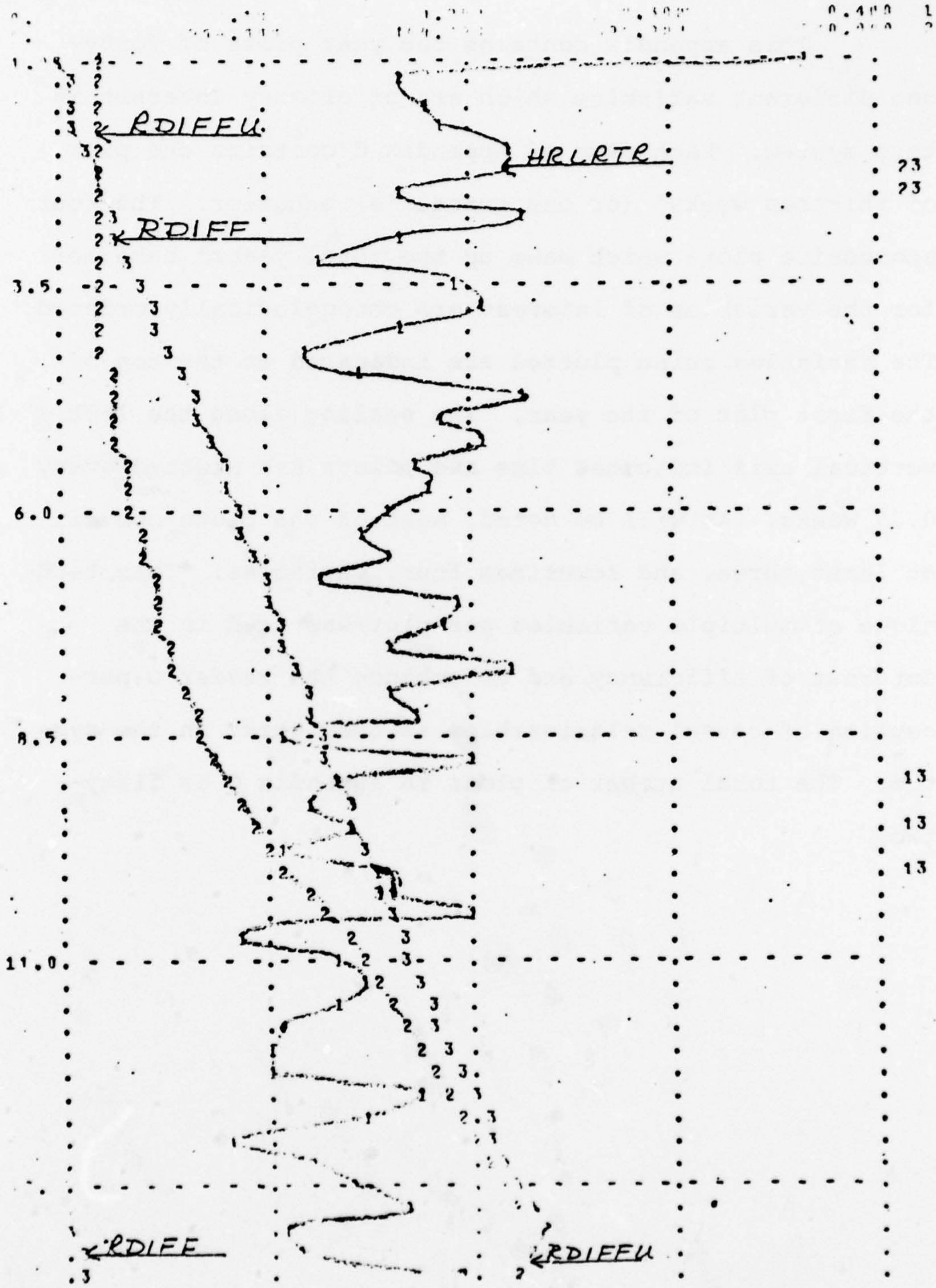
APPENDIX C

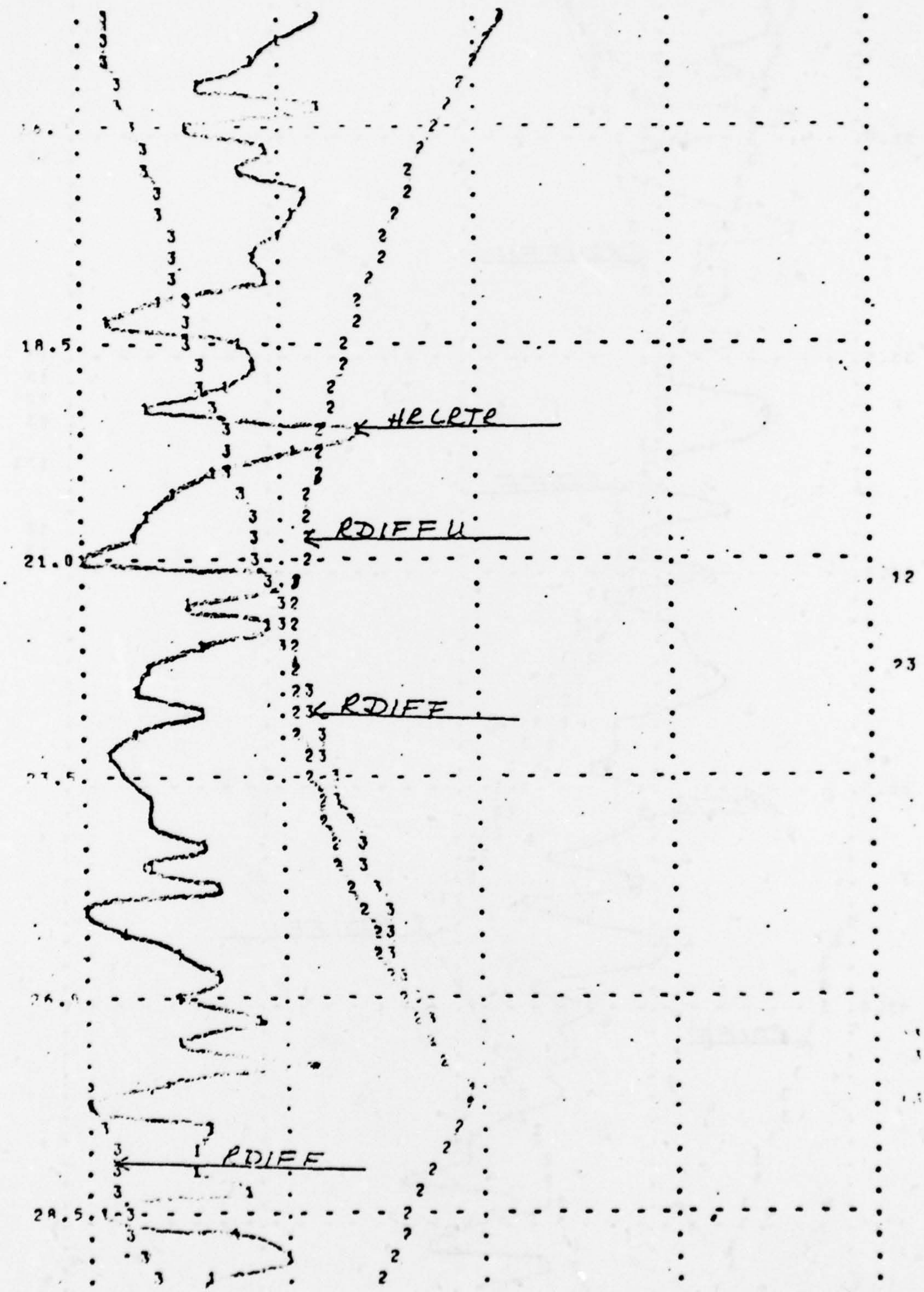
PLOTS OF SYSTEM BEHAVIOR

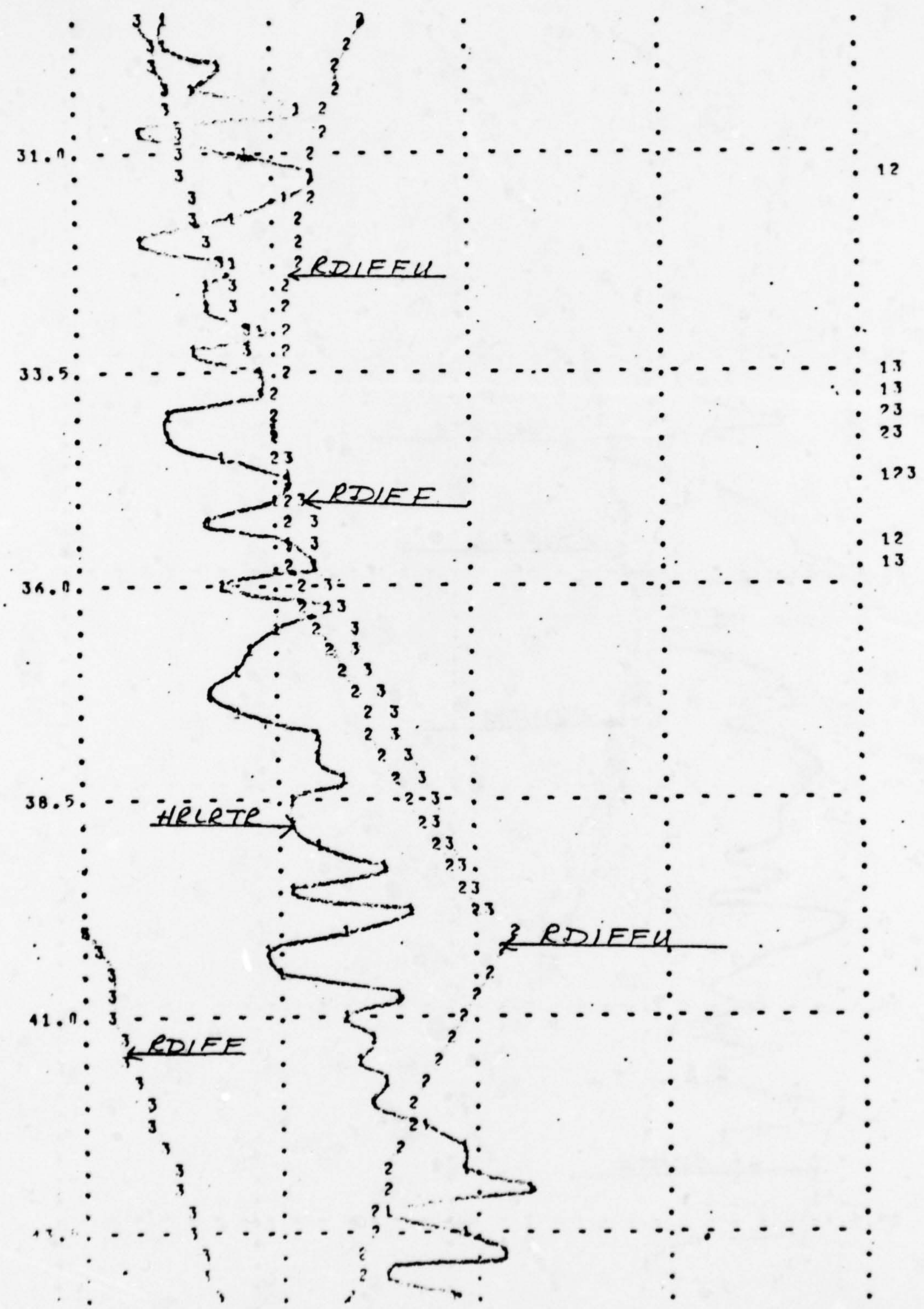
This appendix contains one year plots of forty-one different variables which are of primary interest in this system. Each page of Appendix C contains the plot of thirteen weeks' (or one quarter's) behavior. The four successive plots which make up the total years' behavior for the variables of interest are chronologically ordered. The variables being plotted are indicated at the top of the first plot of the year. The scaling along the left vertical axis indicates time and points are plotted every 0.25 weeks. As will be noted, most of the plots contain at least three, and sometimes four, variables. This technique of multiple variables per plot was used in the interest of efficiency and to enhance the reader's perception of causal relationships as they exist in the system. The total number of plots in Appendix C is fifty-two.

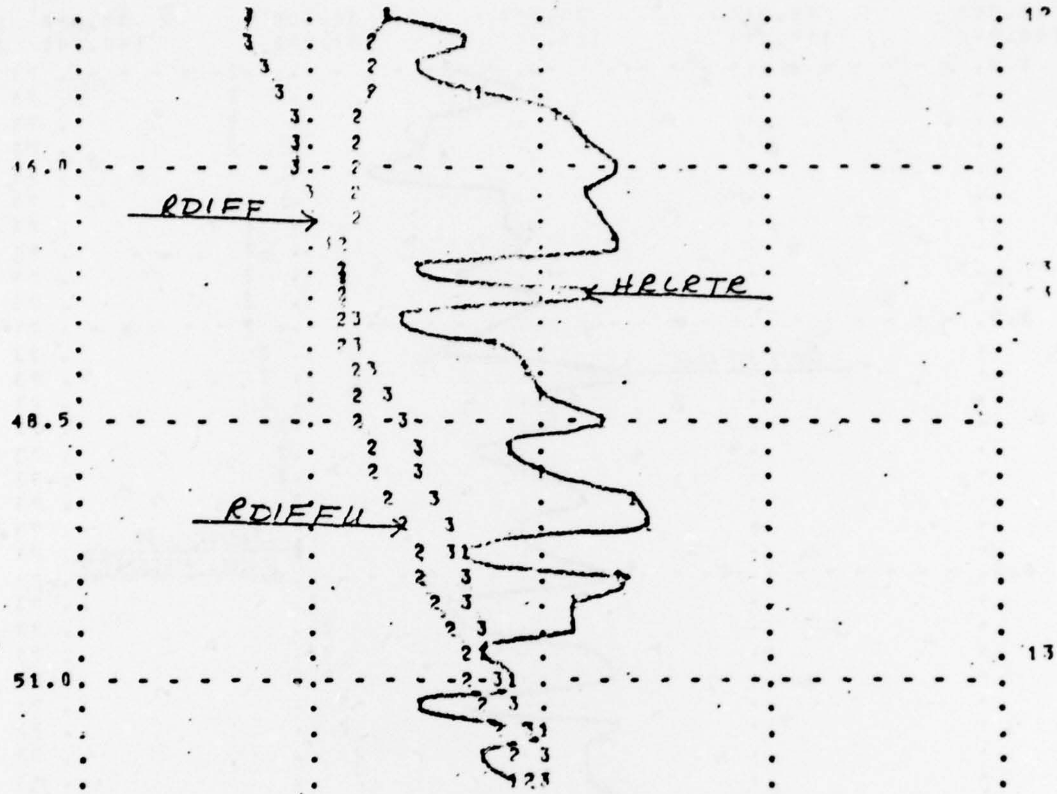
PAGE 8 WING LEVEL SCHEDULING--A SYSTEMIC MODEL BASIC

HPLRTR=1 RDIFFU=2 RDIFF=3



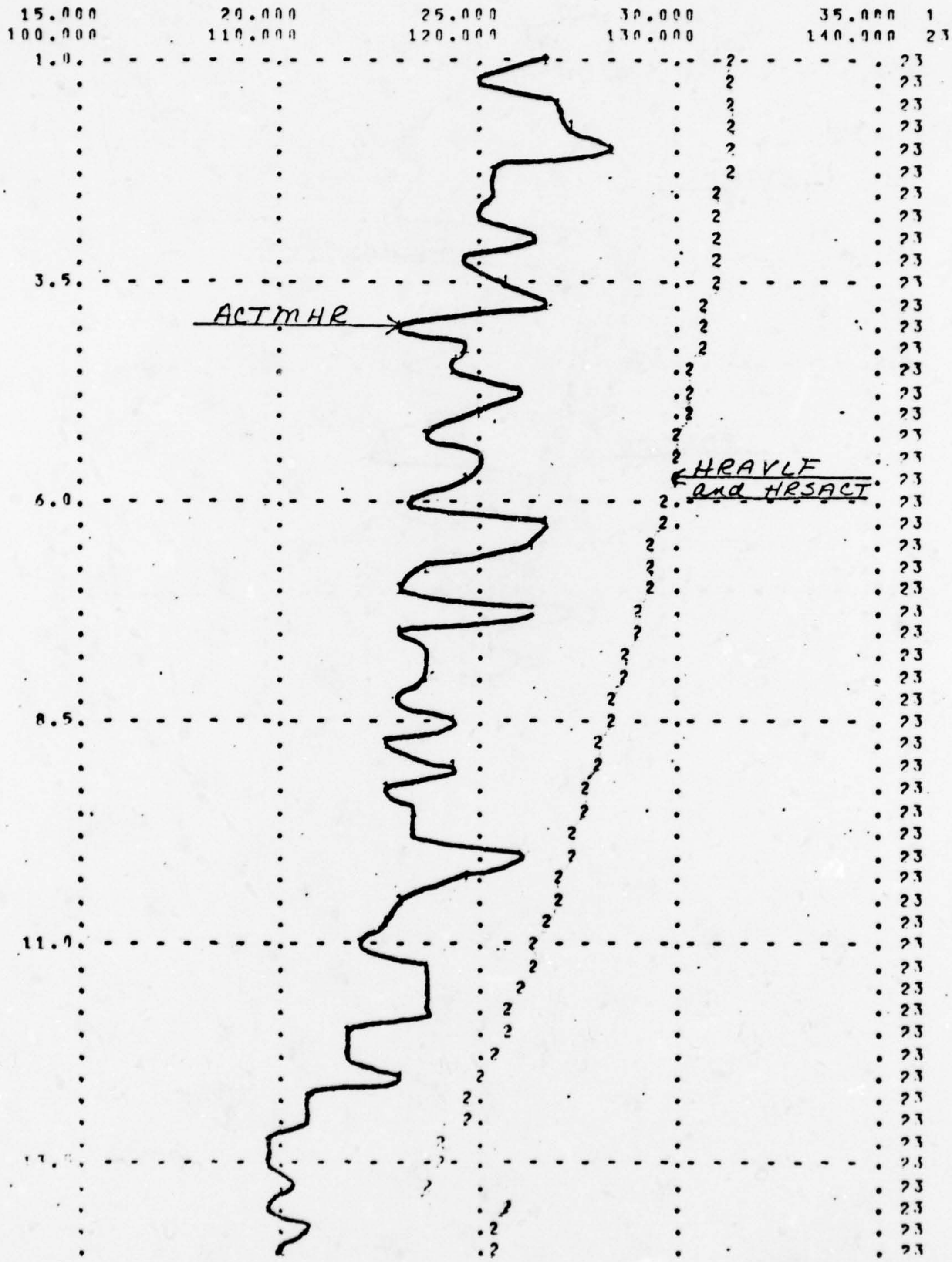

18.5
21.0
28.5
HRCRTC
RDIFFU
RDIFF
RDIFF

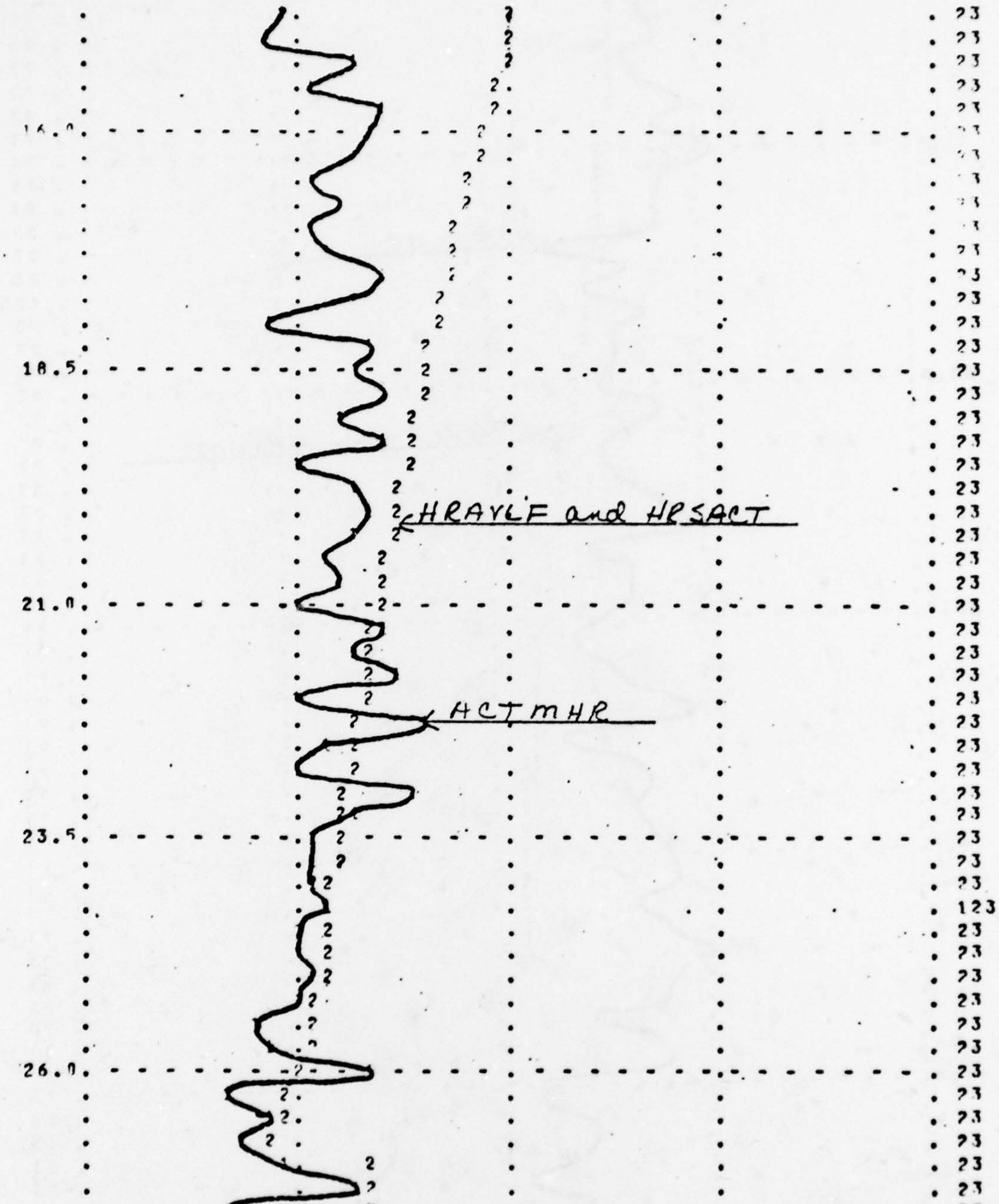

31.0
33.5
36.0
38.5
41.0
RDIFFU
RDIFF
HRLRTR
RDIFFU
RDIFF
12
13
13
23
23
123
12
13


48.5
51.0
RDIFF
RDIFFU
HRCRTR
13

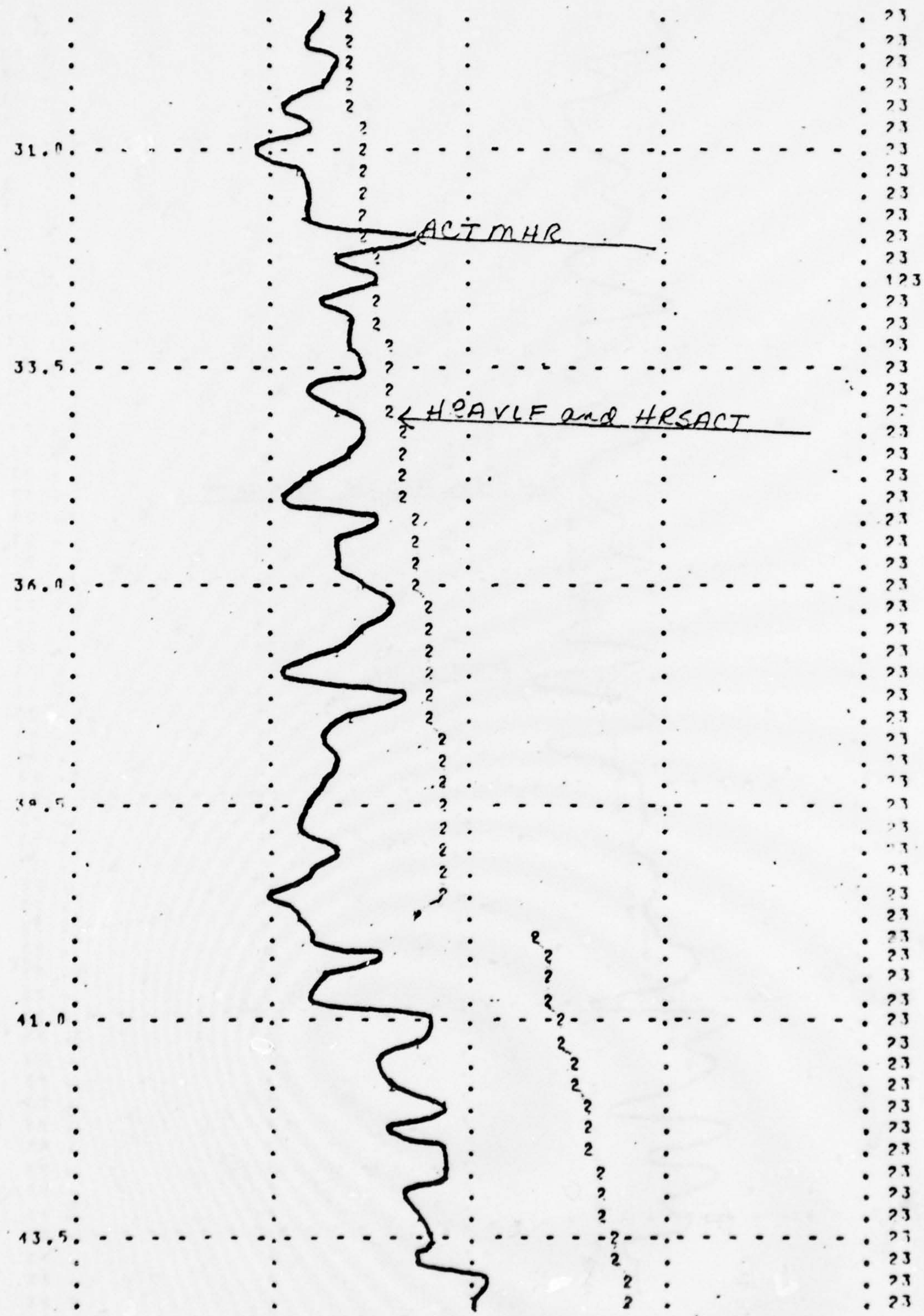
PAGE 9 WING LEVEL SCHEDULING--A SYSTEMIC MODEL BASIC

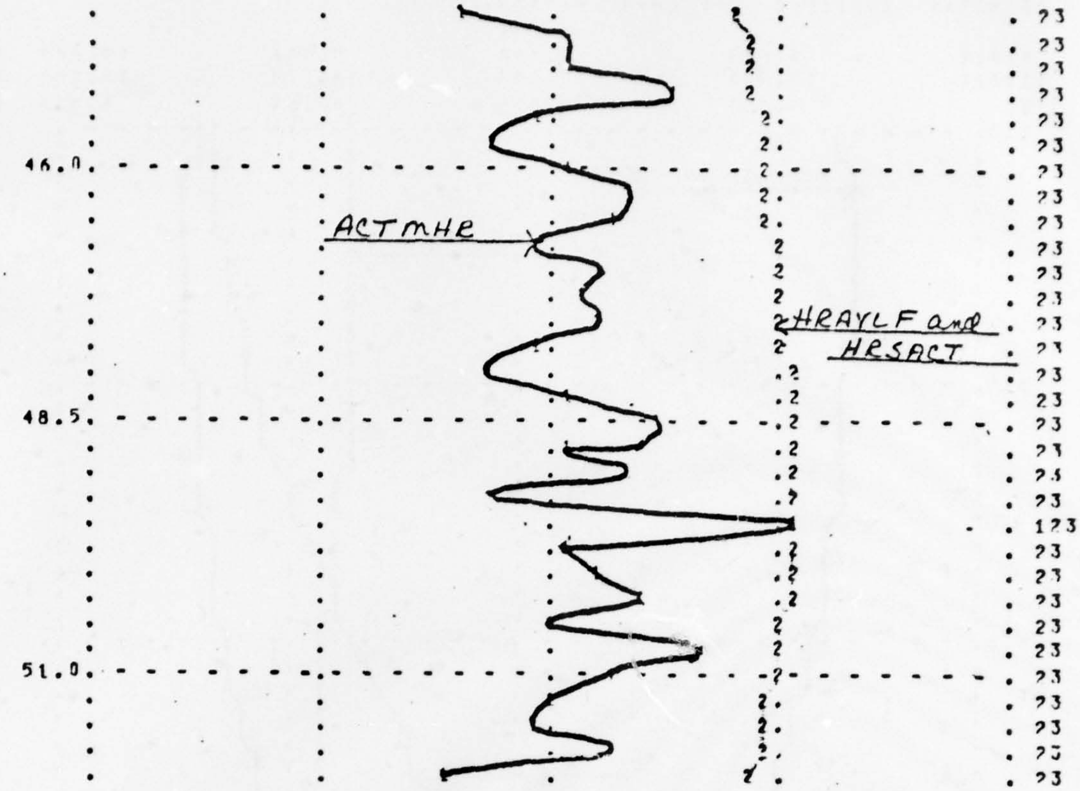
ACTMHR=1 HRAVLF=2 HRSACT=3





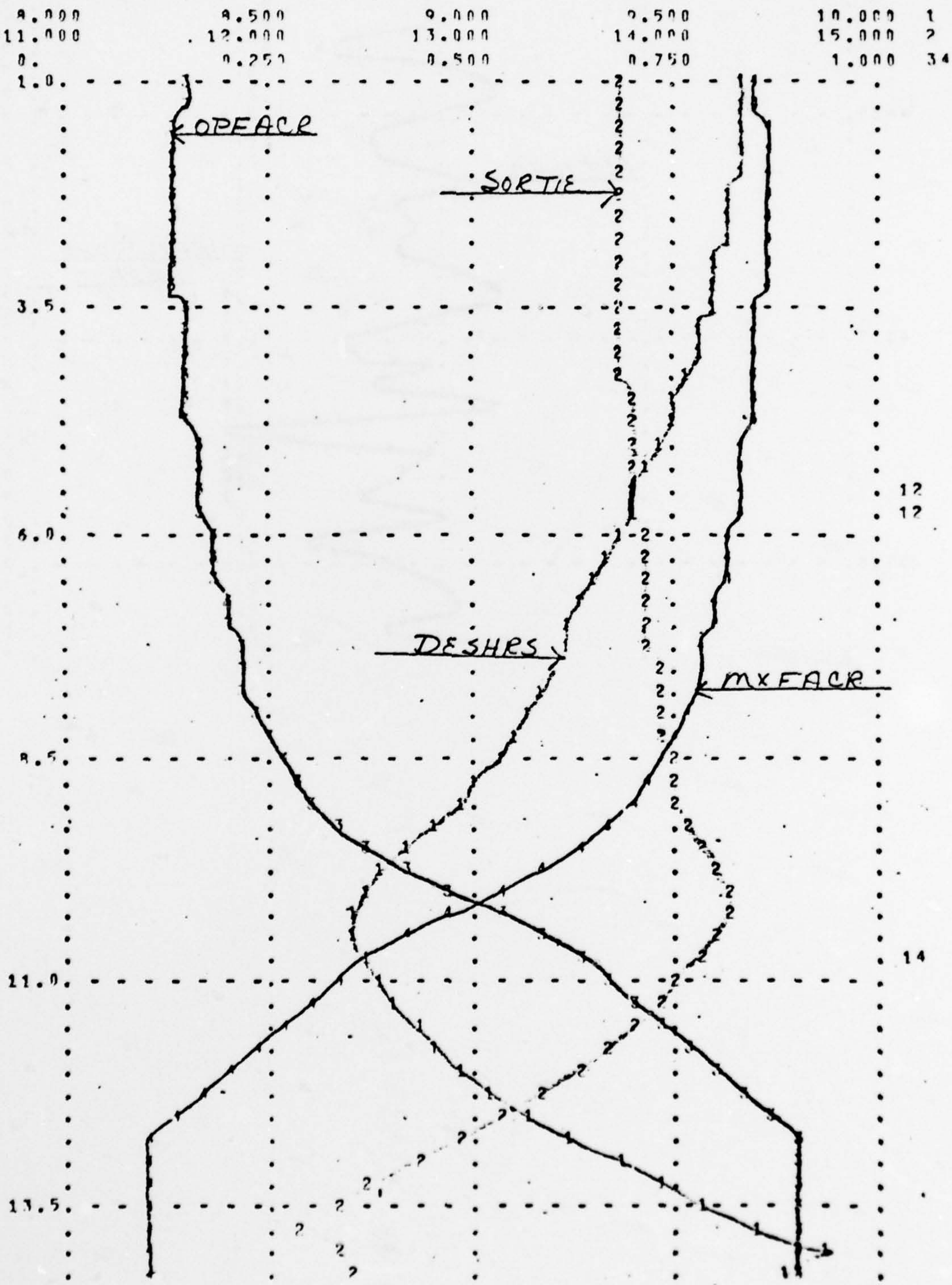
16.0
18.5
21.0
23.5
26.0
28.5
HRAYLF and HRSACT
ACTMHR

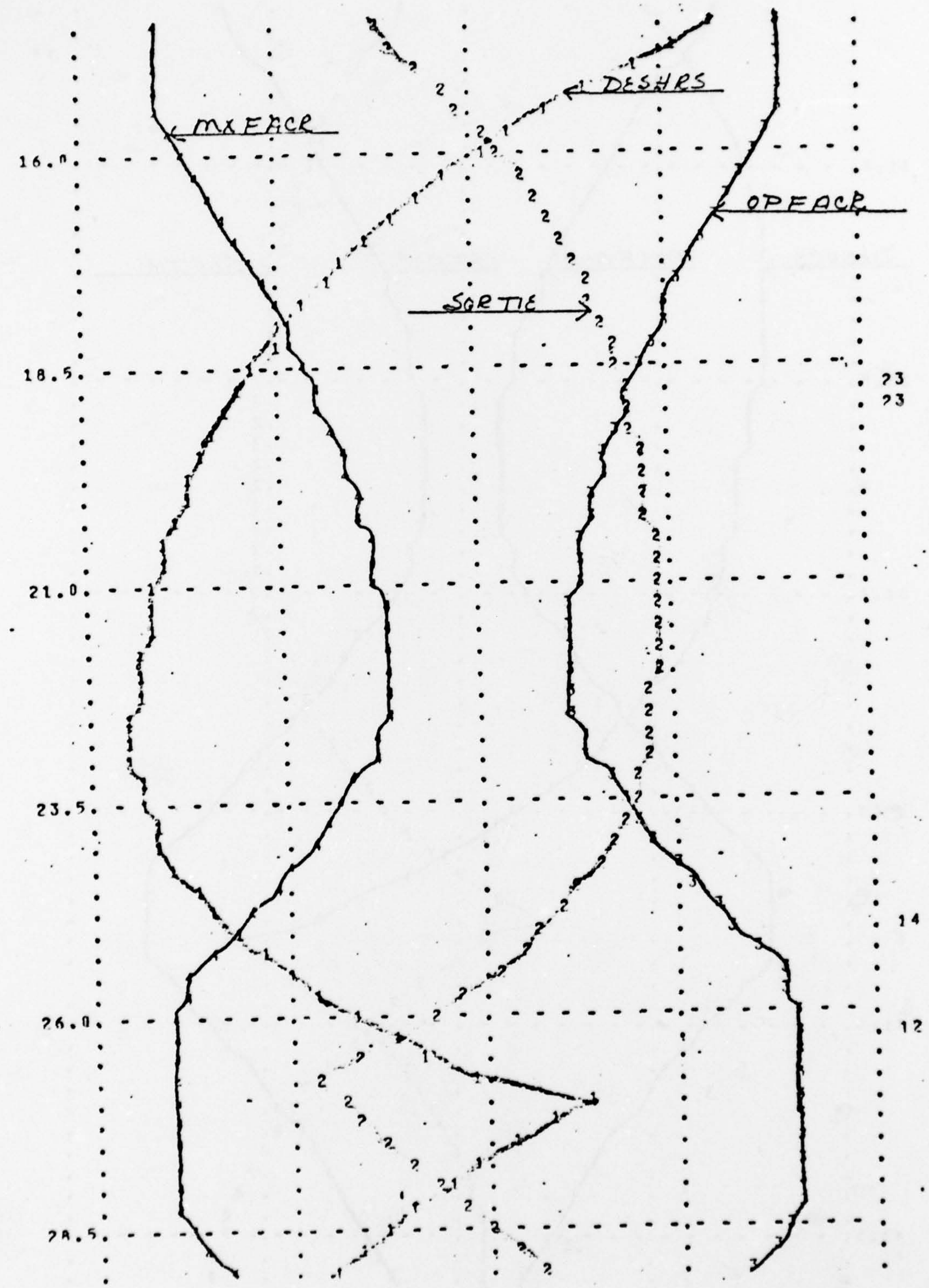

31.0
33.5
36.0
38.5
41.0
43.5
ACTMHR
H°AVLF and HRSACT

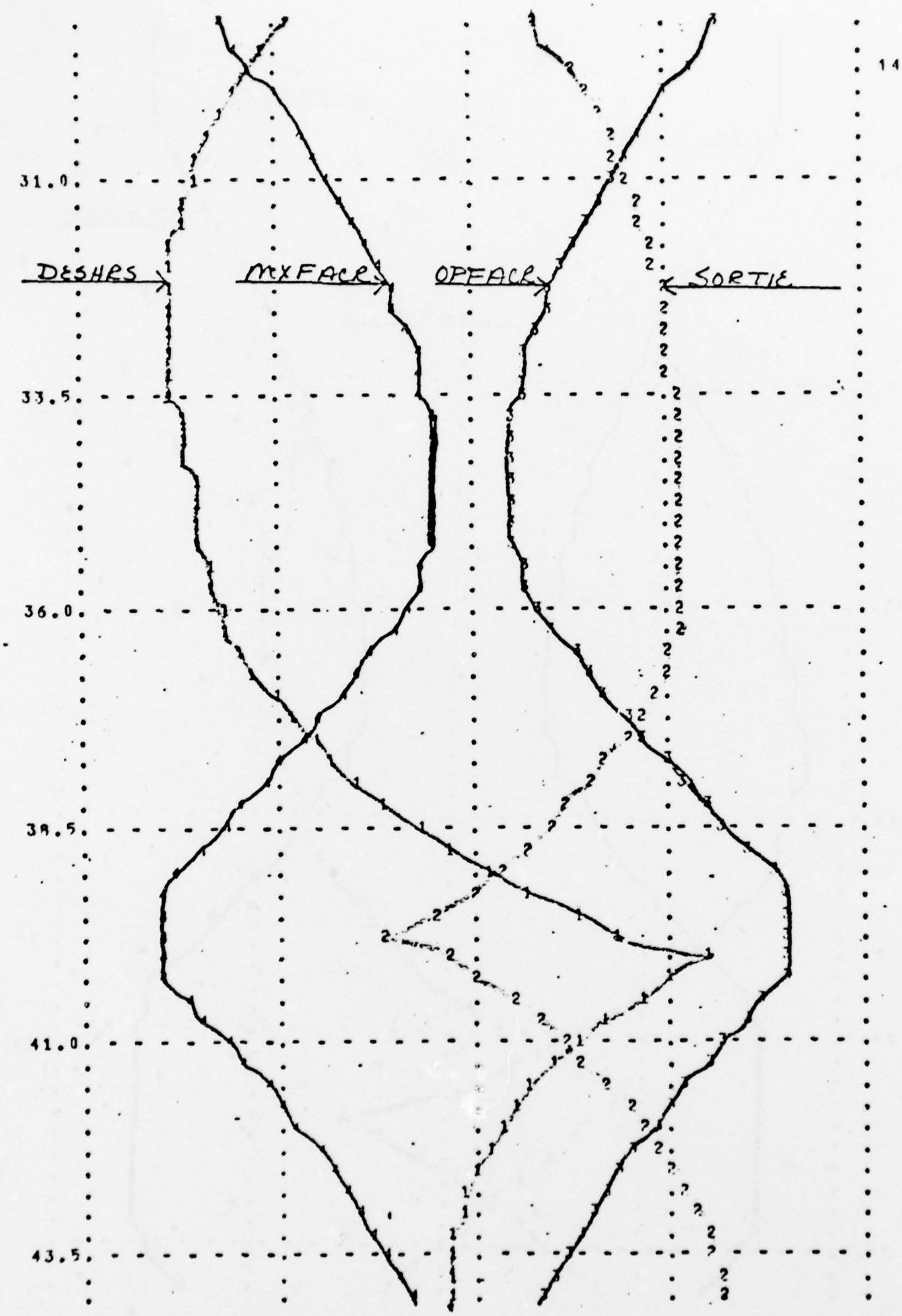

46.0
48.5
51.0
ACTMHR
HRAYLF and
HRSACT

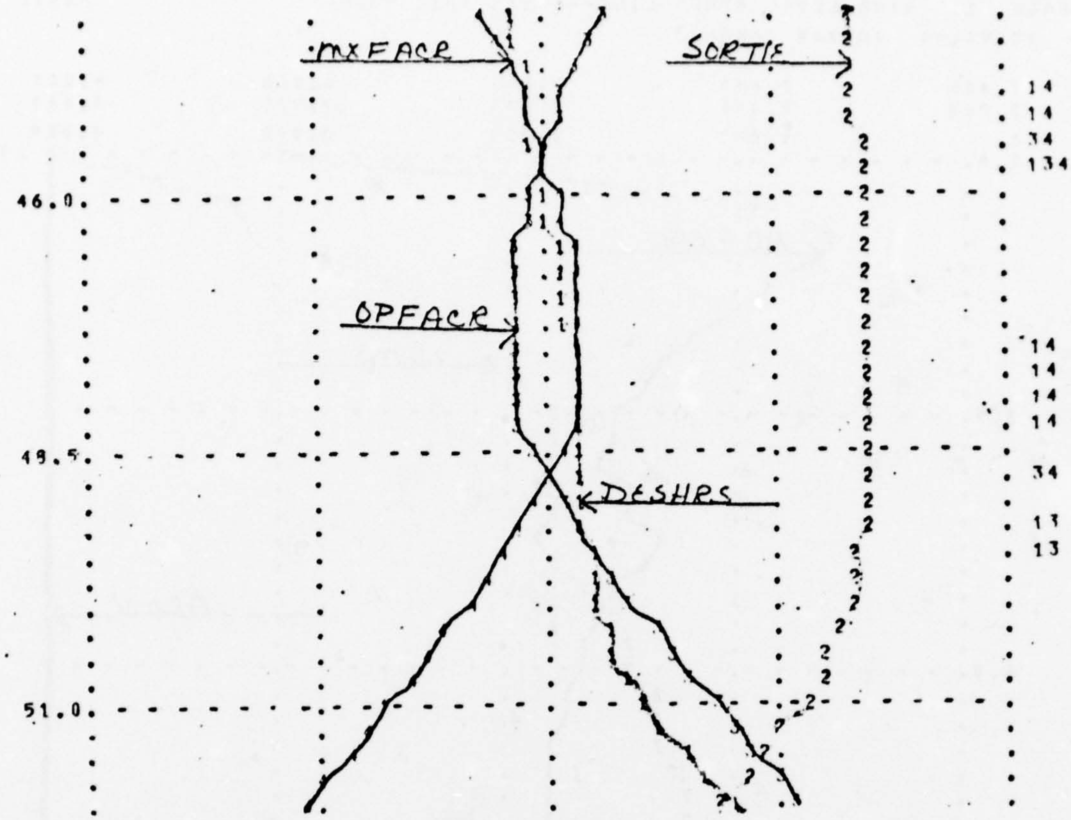
PAGE 10 WING LEVEL SCHEDULING--A SYSTEMIC MODEL BASIC

DESHRS=1 SORTIE=2 OPFACR=3 MXFACR=4




MXEACR
DESHRS
OPEACR
SORTIE
16.0
18.5
21.0
23.5
26.0
28.5
23
23
14
12

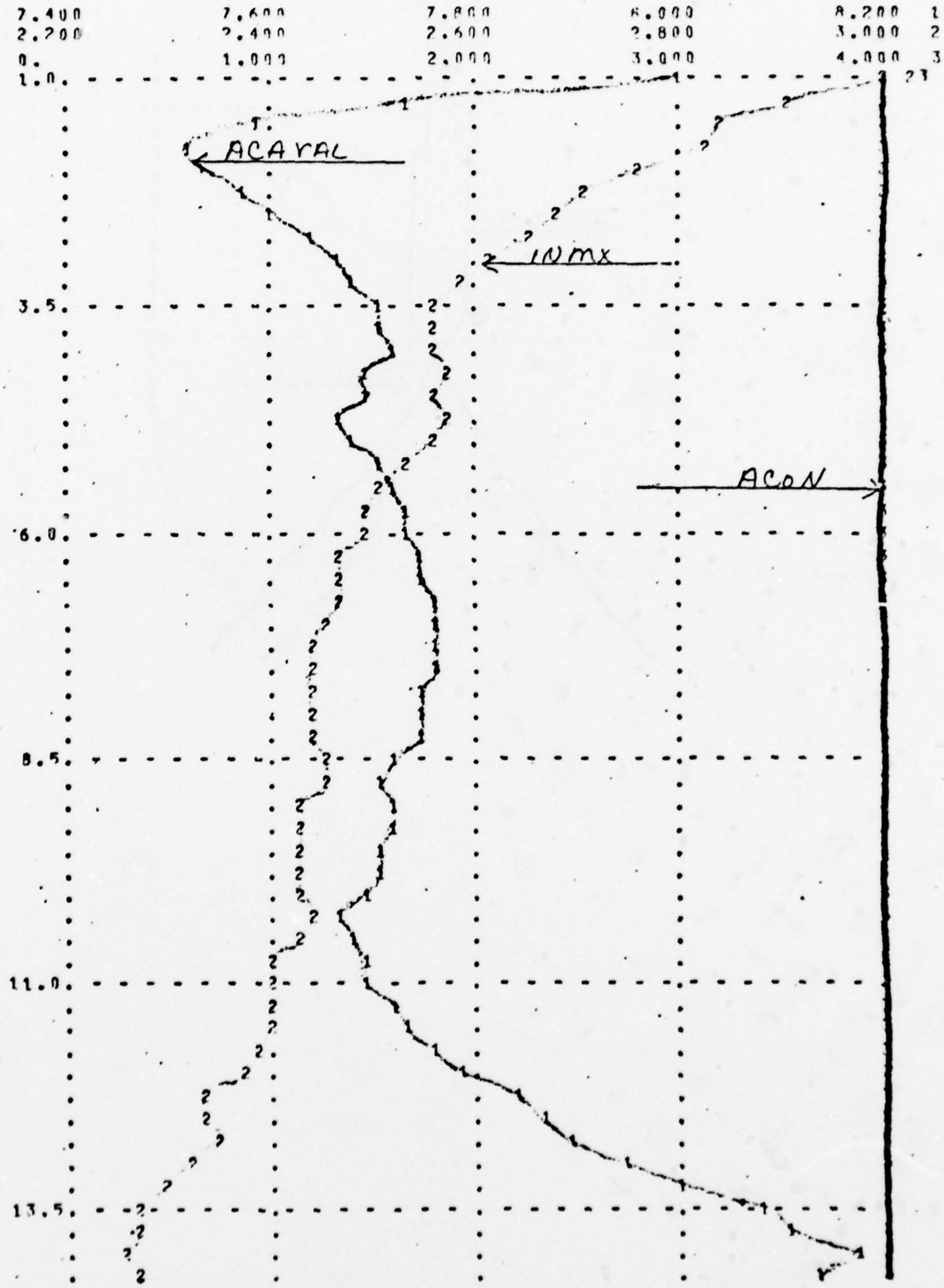

14
31.0
33.5
36.0
38.5
41.0
43.5
DESHRS
MXFACR
OPFACR
SORTIE

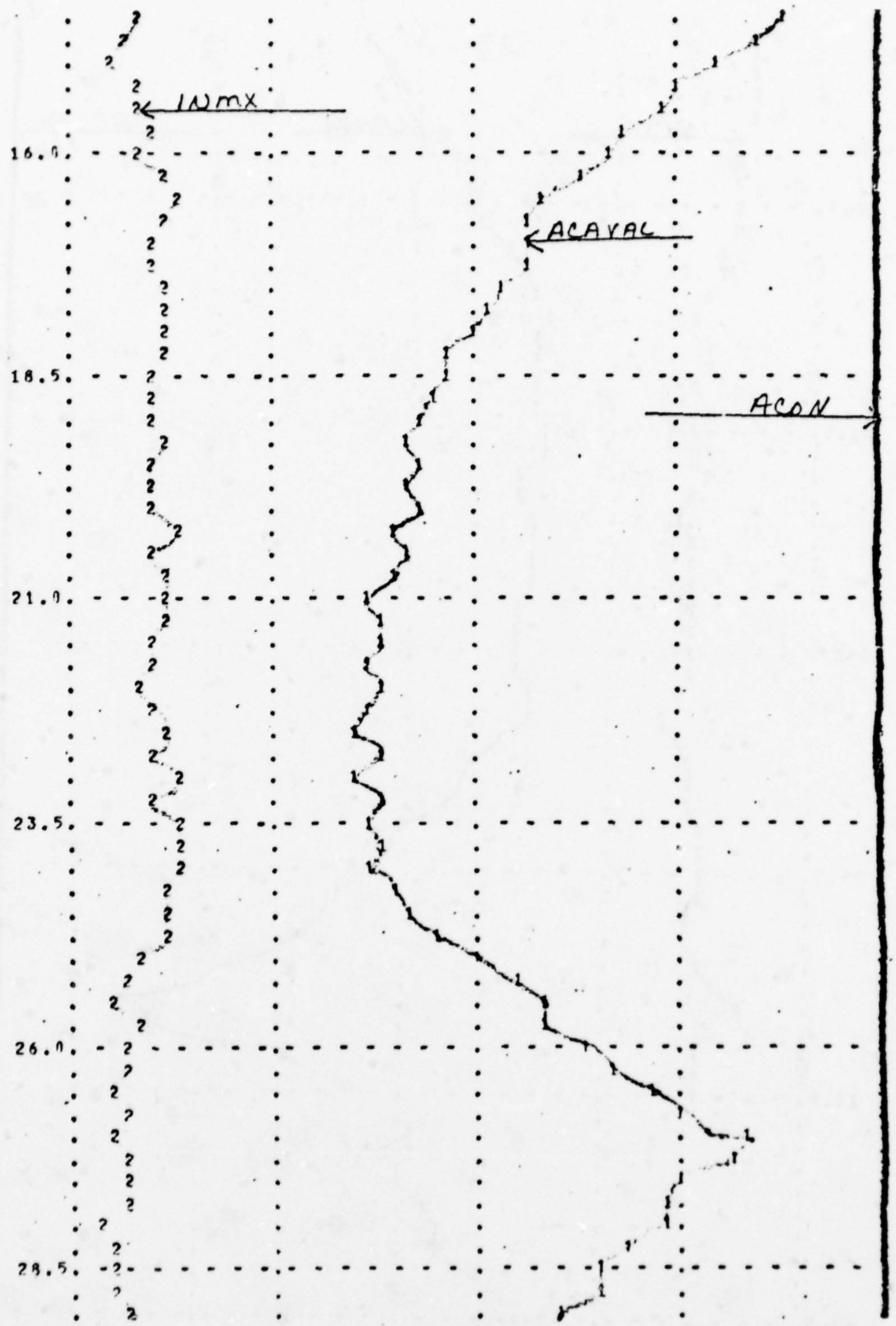


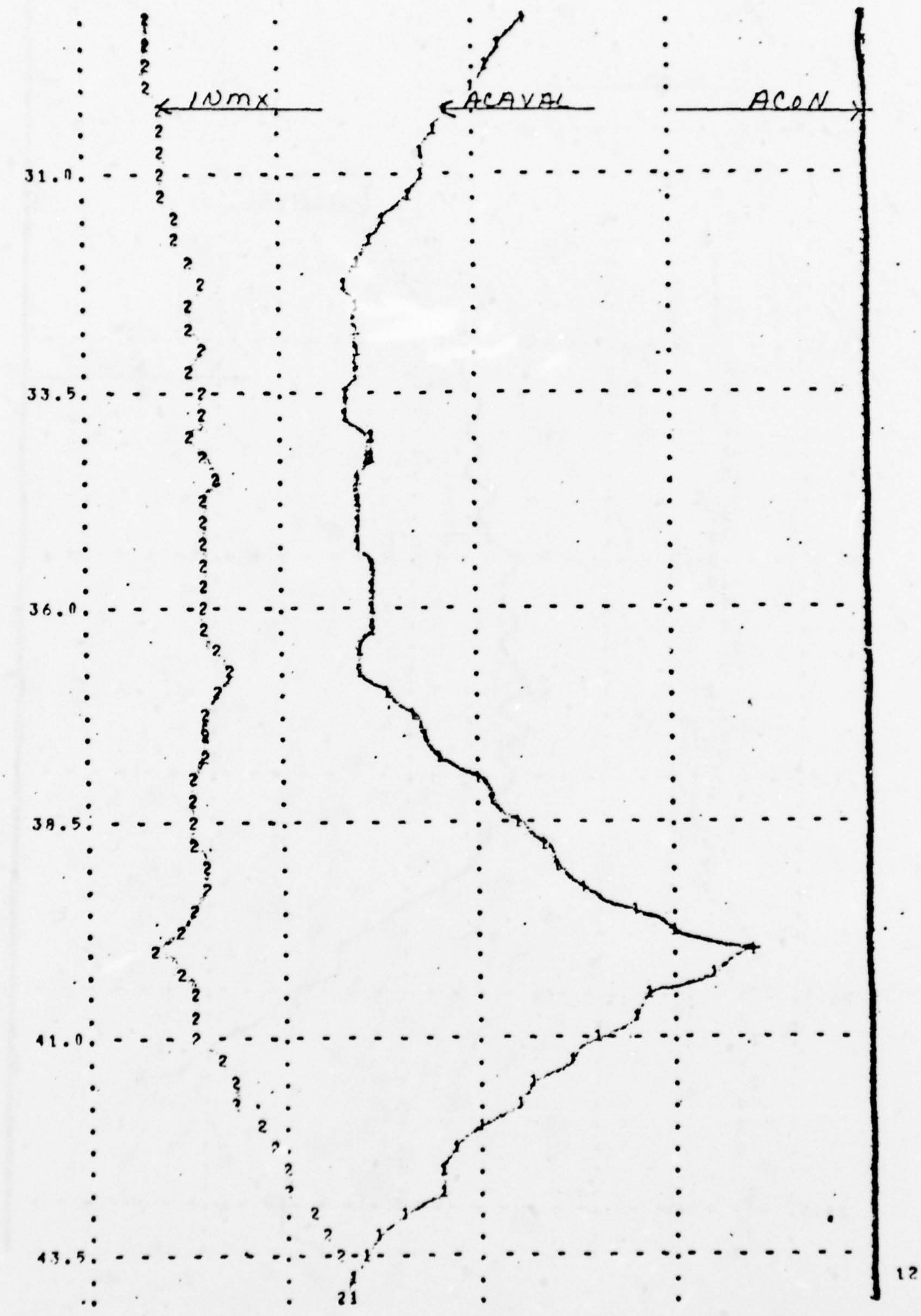
MXFACR
SORTIE
OPFACR
DESHRS
46.0
49.5
51.0

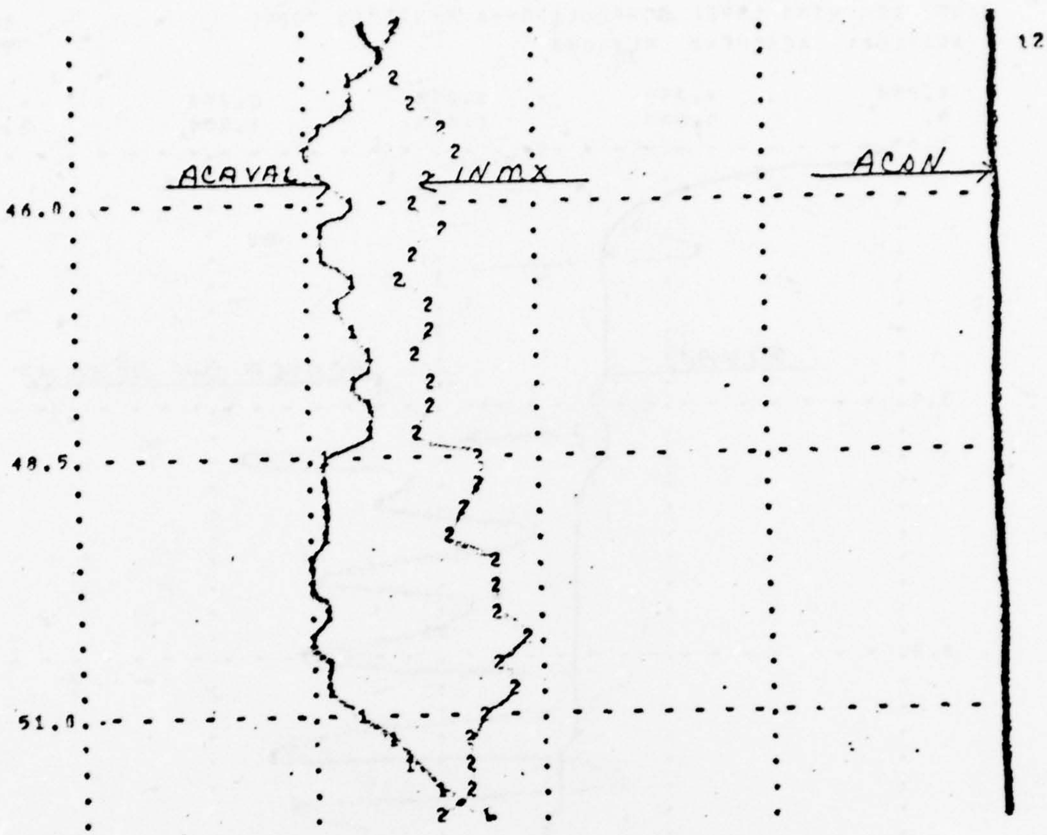
PAGE 11 WING LEVEL SCHEDULING--A SYSTEMIC MODEL BASIC

ACAVAL=1 INMX=2 ACON=3



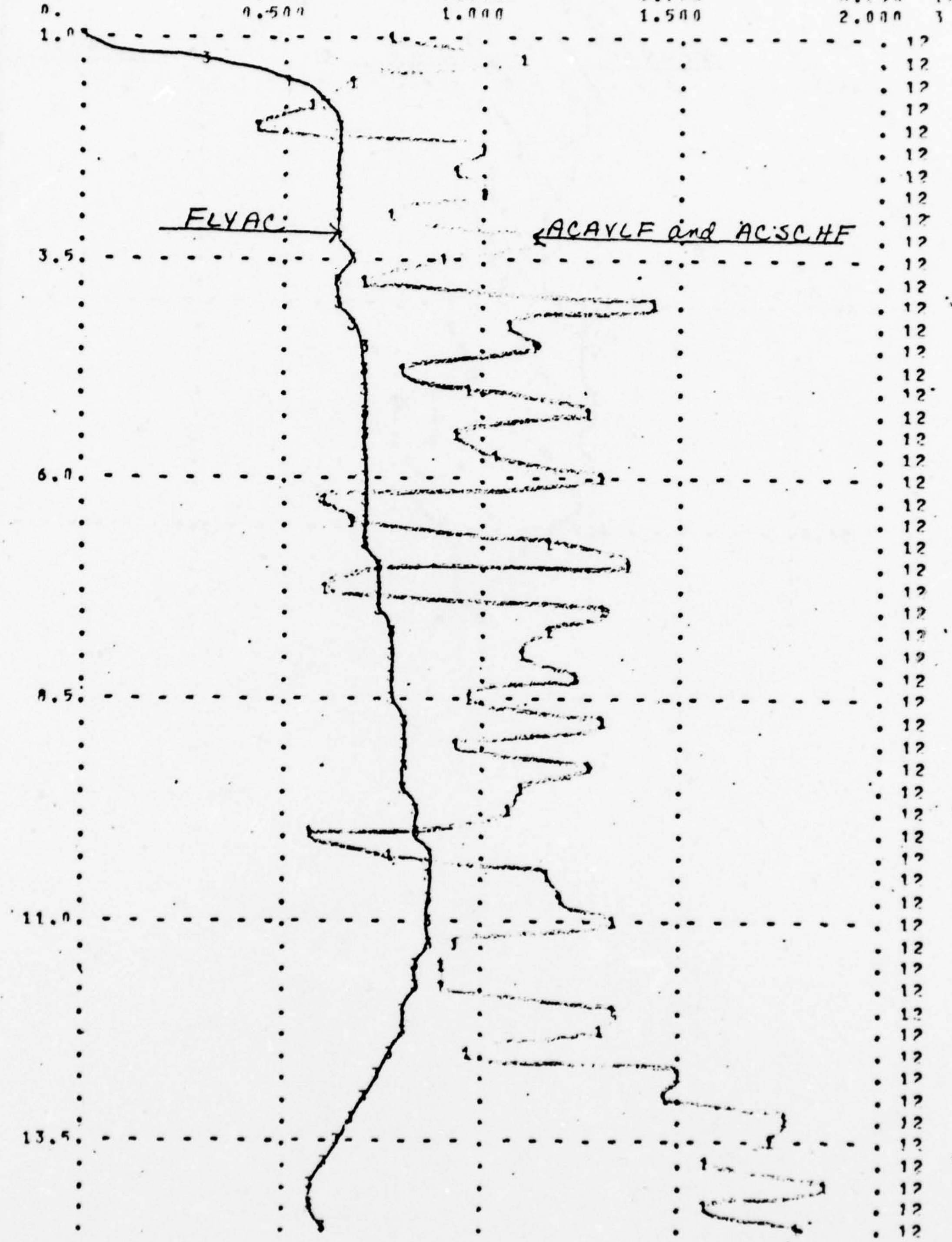

IWMX
ACAVAL
ACON
16.0
18.5
21.0
23.5
26.0
28.5

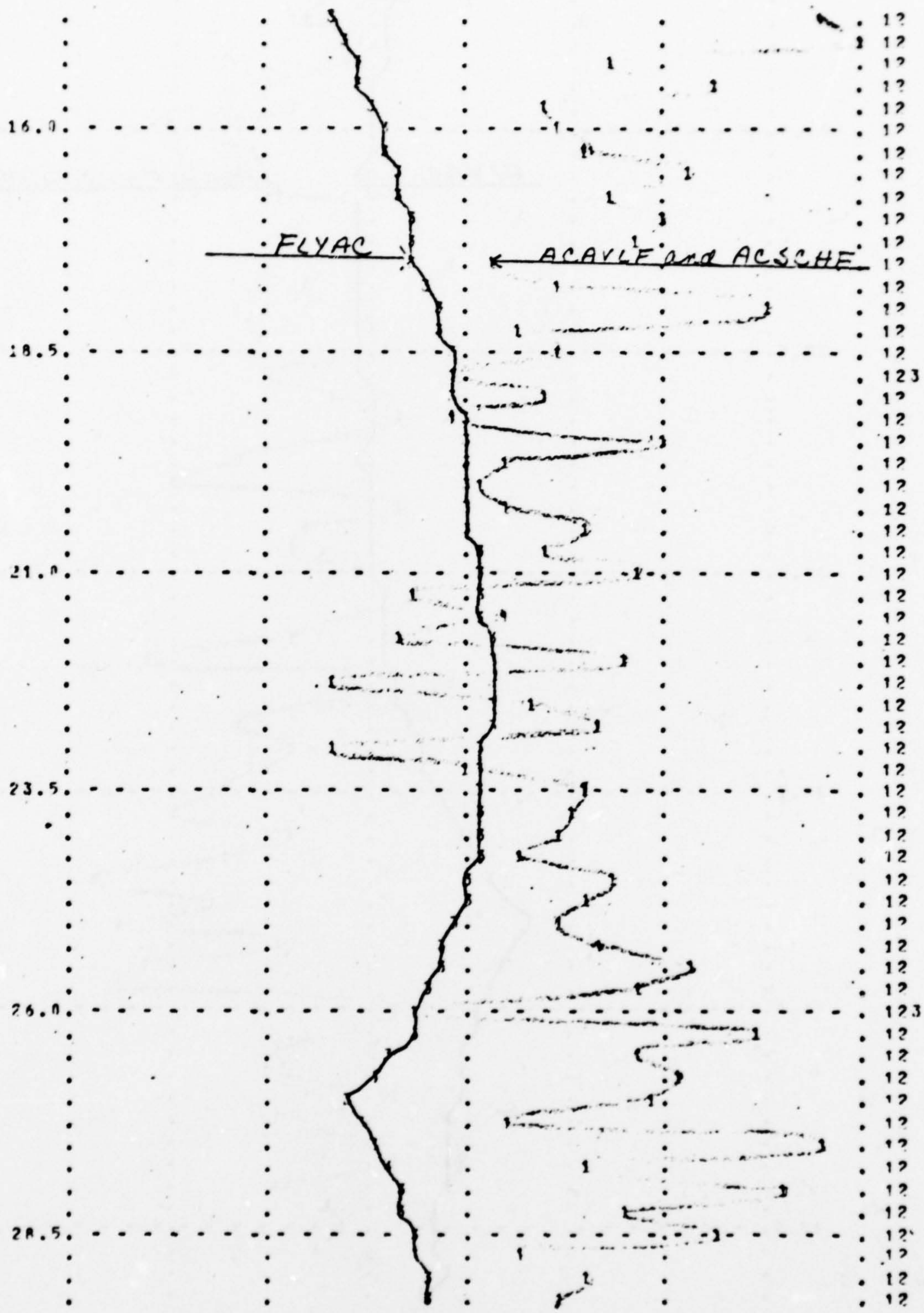

INMX
ACAVAL
ACON
31.0
33.5
36.0
38.5
41.0
43.5
12



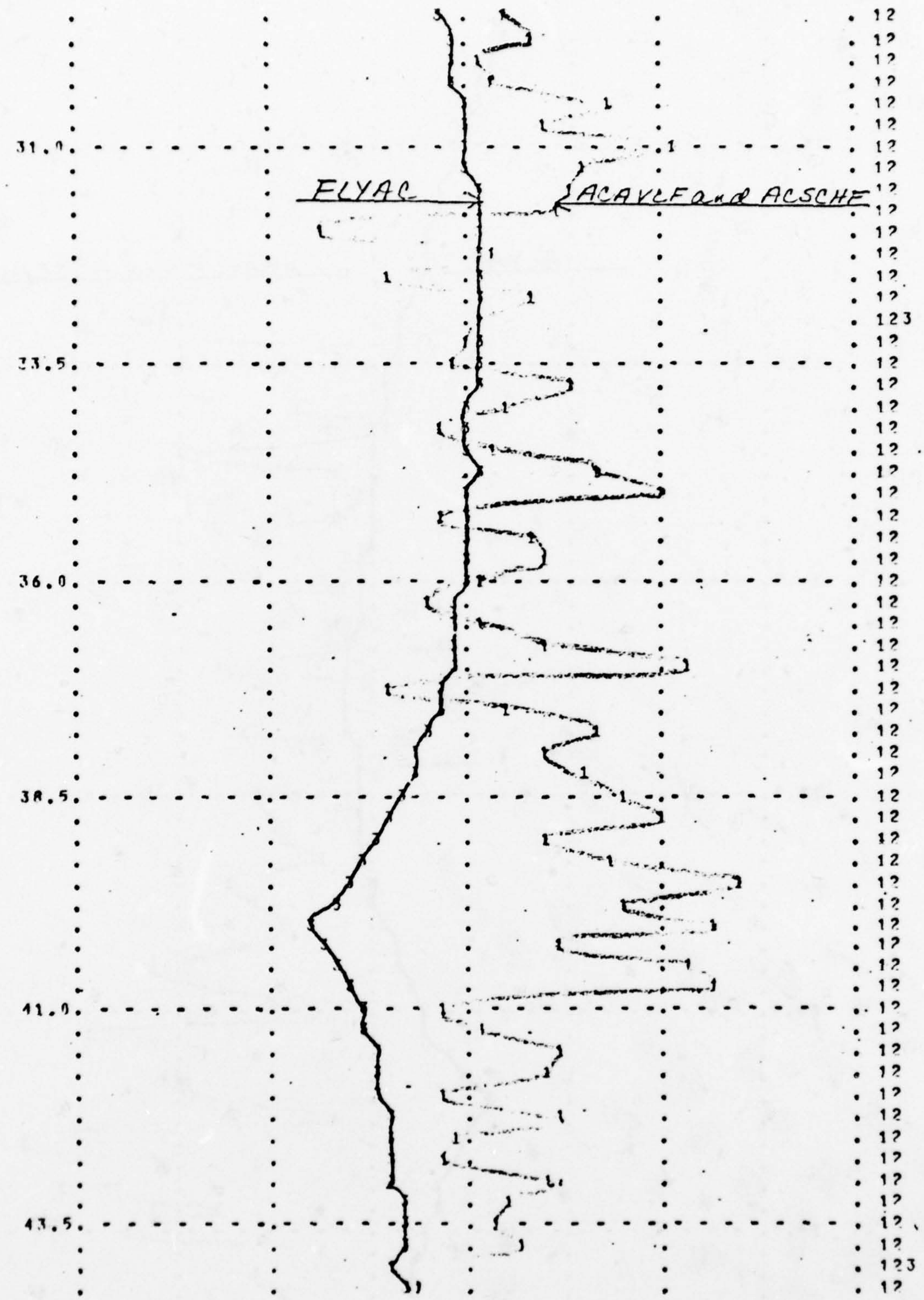
12
ACAVAL
INMX
ACAN
46.0
48.5
51.0

ACAVLF=1 ACSCHF=2 FLYAC=3

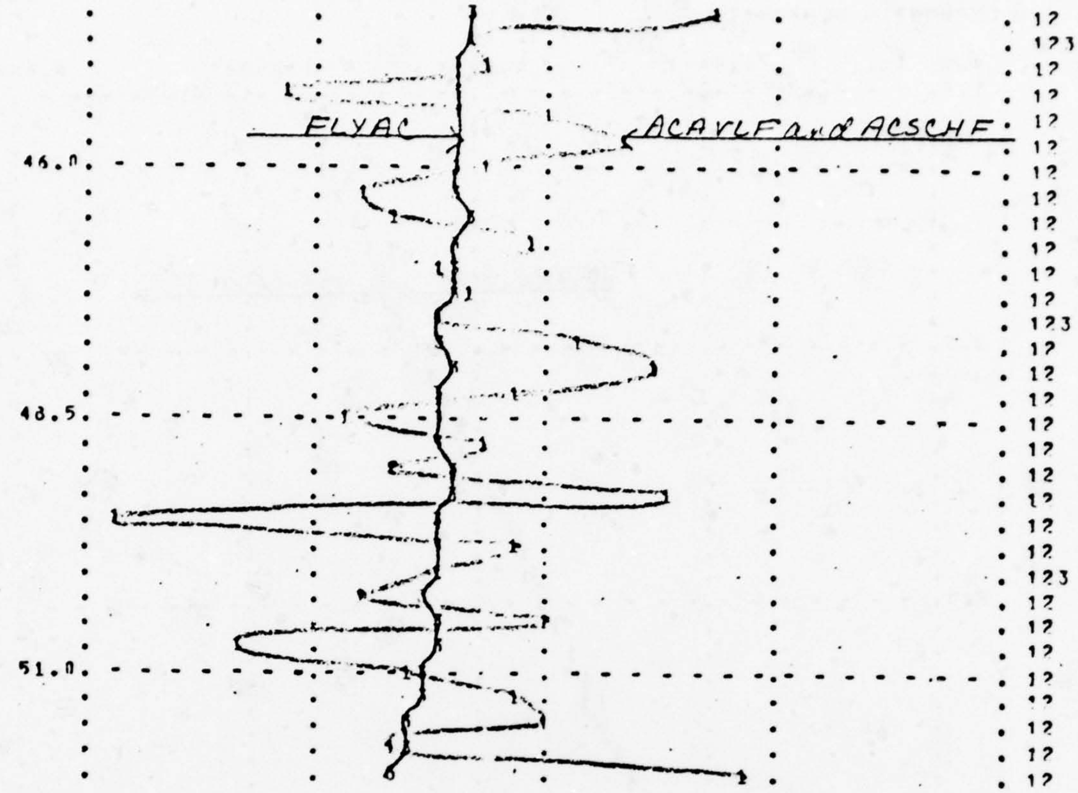




16.0
18.5
21.0
23.5
26.0
28.5
FLYAC
ACAVLF and ACSCHE

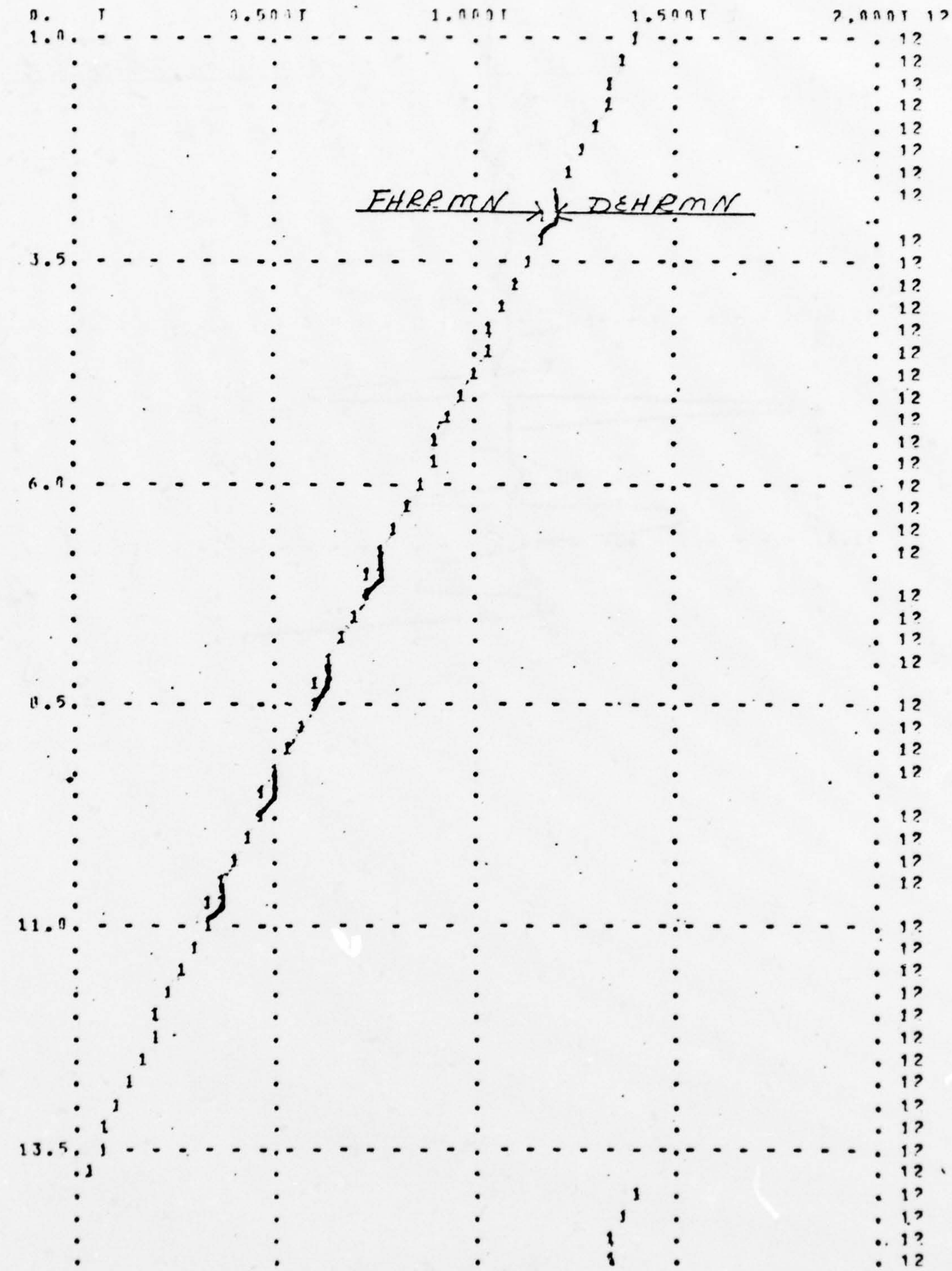


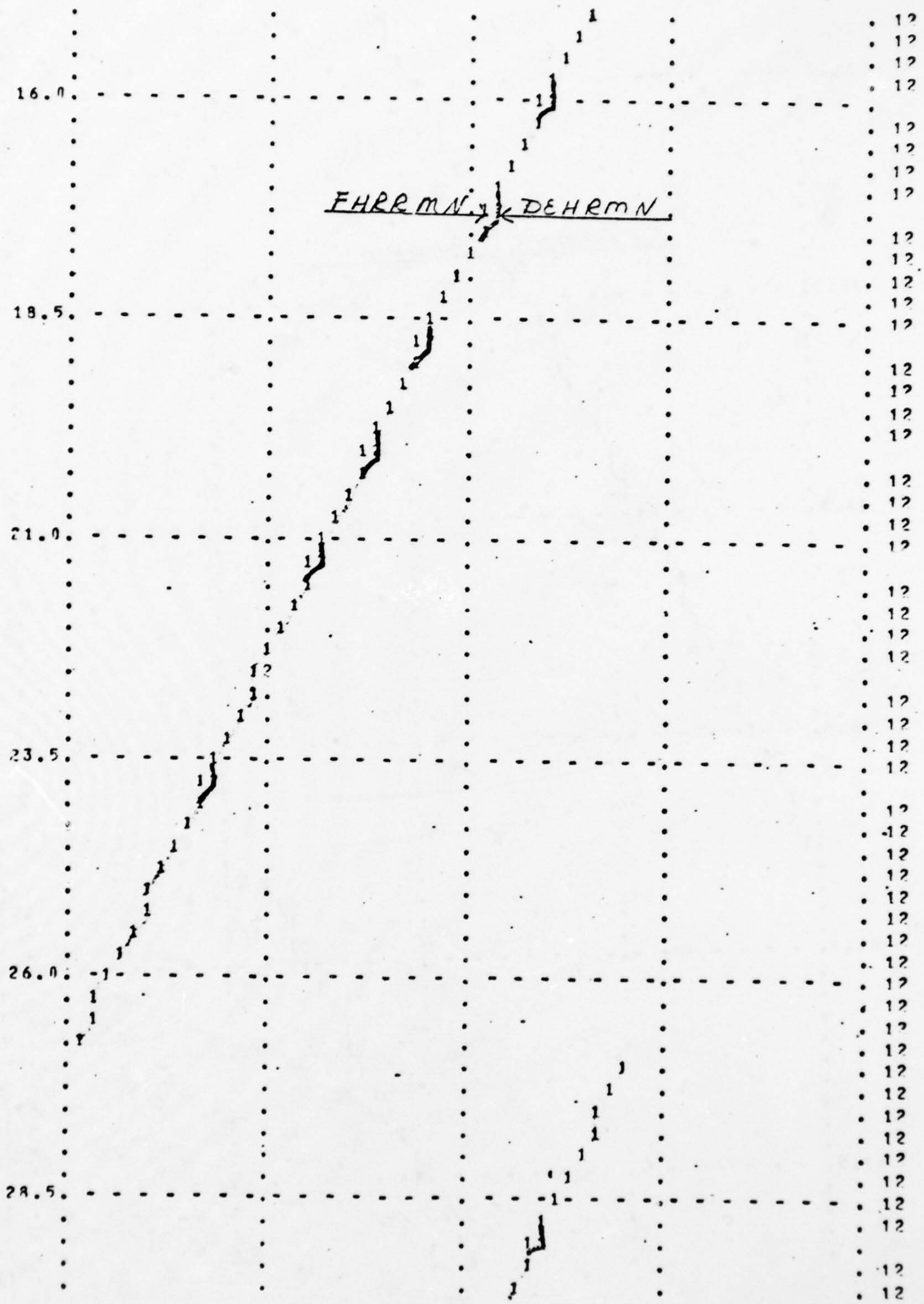
31.0
33.5
36.0
38.5
41.0
43.5
ELYAC
ACAVLF and ACSCHF

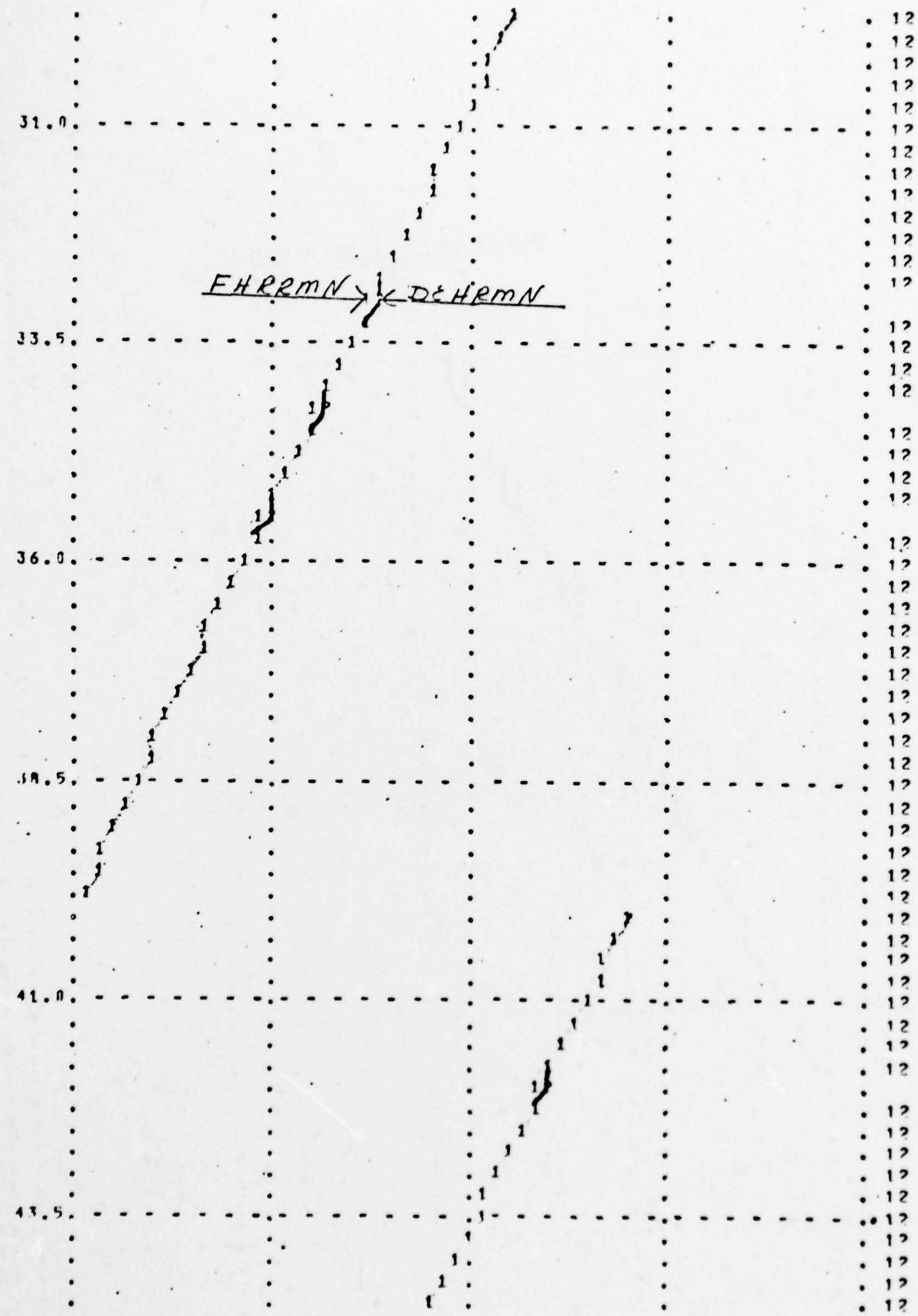


FLYAC
ACAVLF and ACSCHF
46.0
48.5
51.0

FHRRMN=1 DEHRMN=2



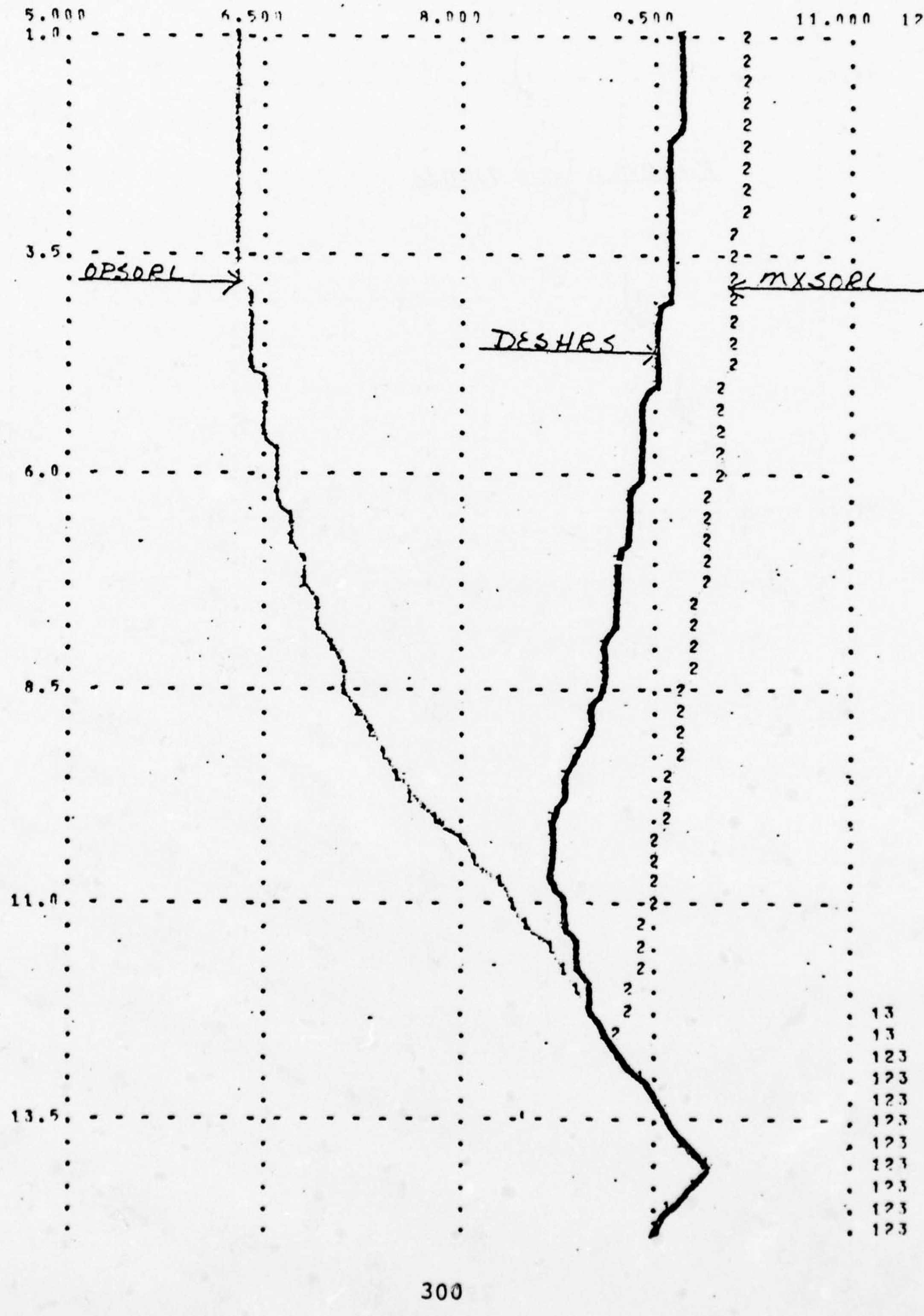

FHRRMN
DEHRMN
16.0
18.5
21.0
23.5
26.0
28.5

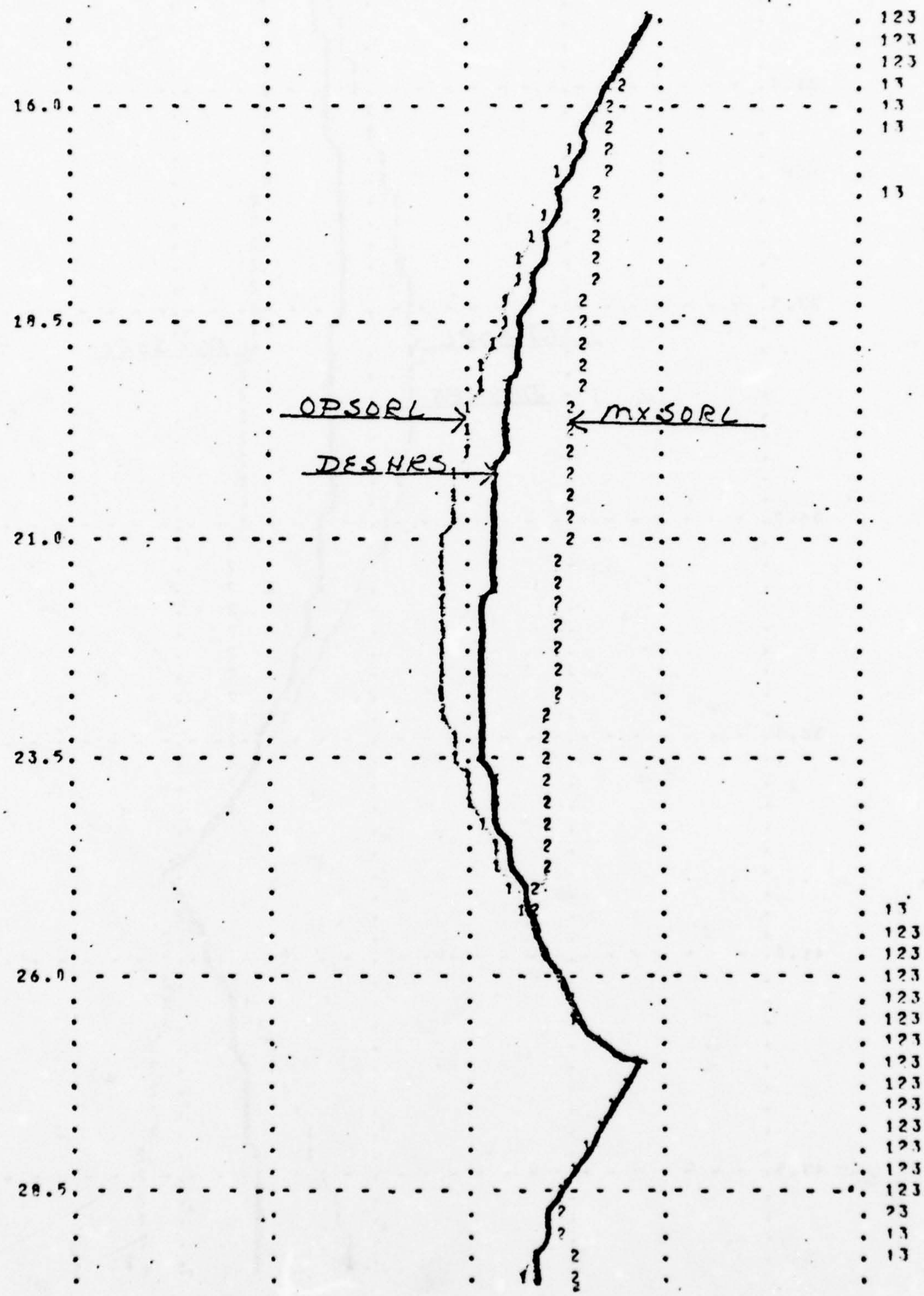

31.0
33.5
36.0
38.5
41.0
43.5
EHRRMN
DEHRMN

46.0
48.5
51.0
EHRRMN
DEHRMN

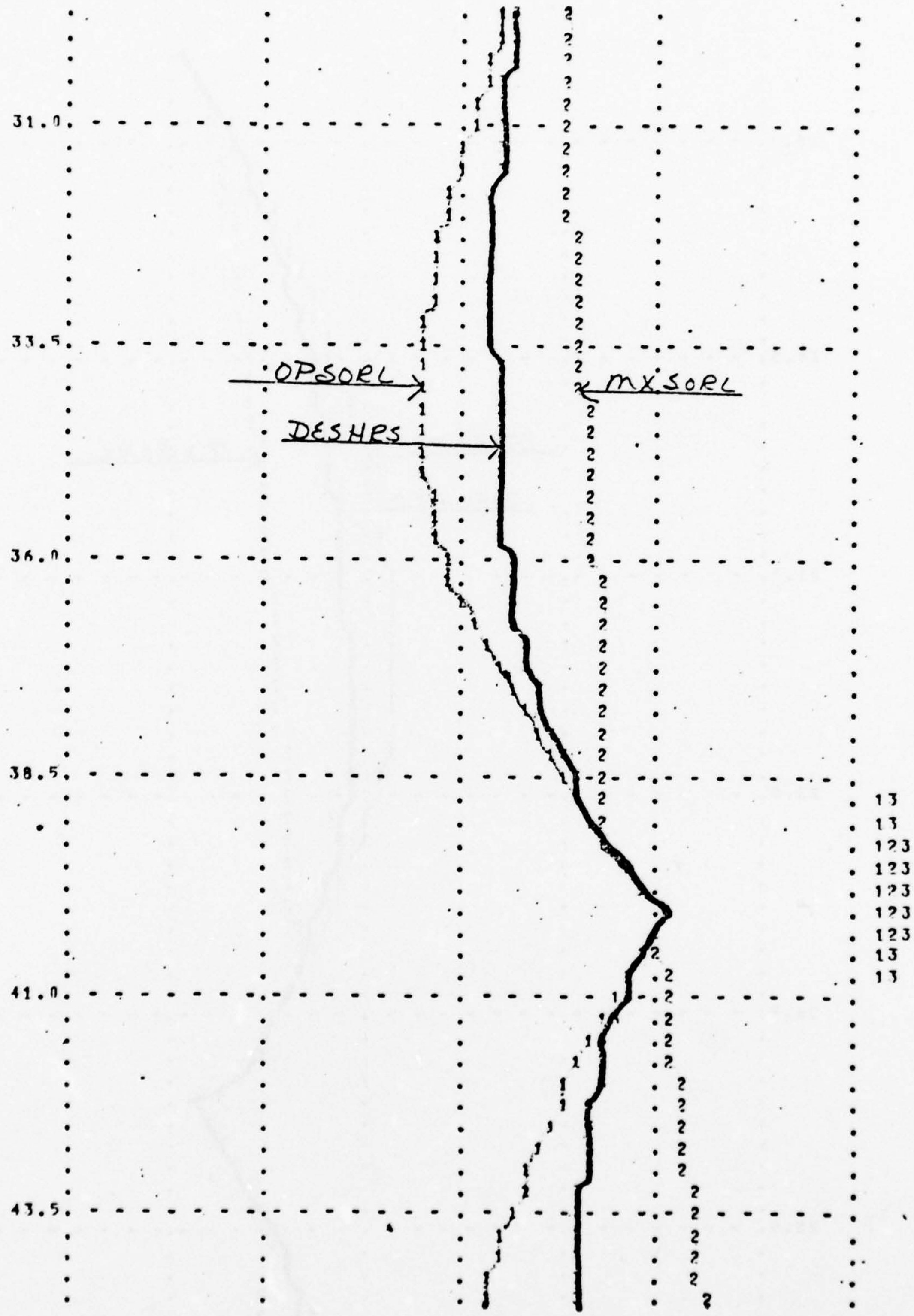
PAGE 14 WING LEVEL SCHEDULING--A SYSTEMIC MODEL . BASIC

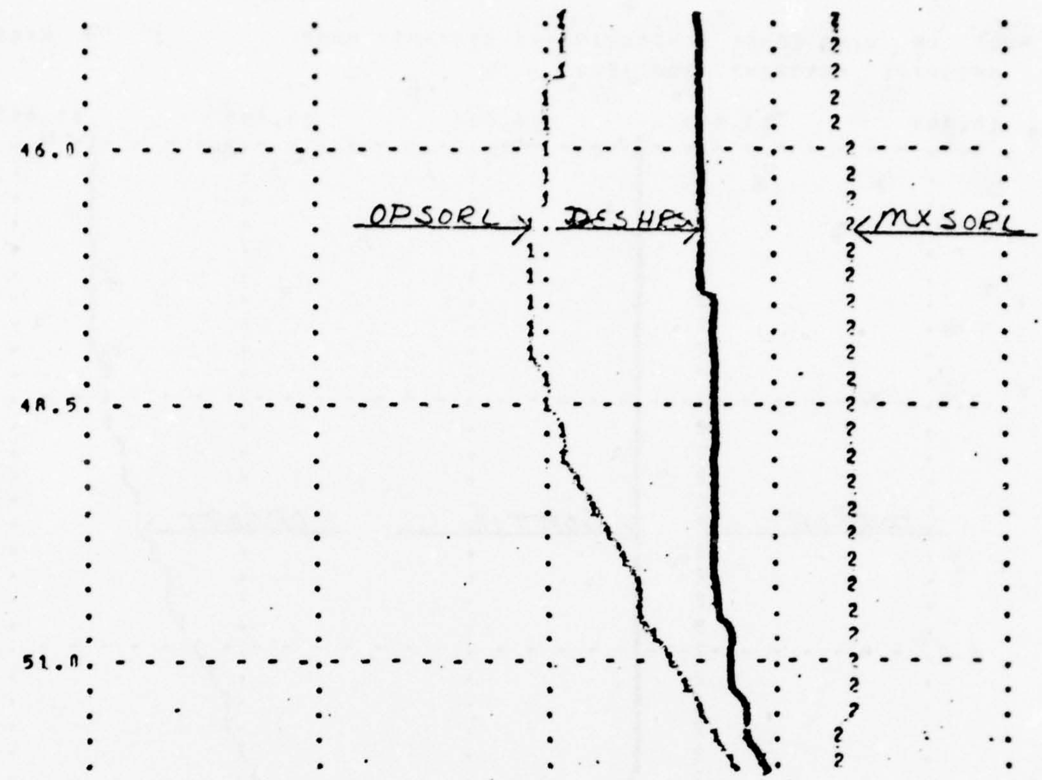
OPSORL=1 MXSORL=2 DESHRS=3





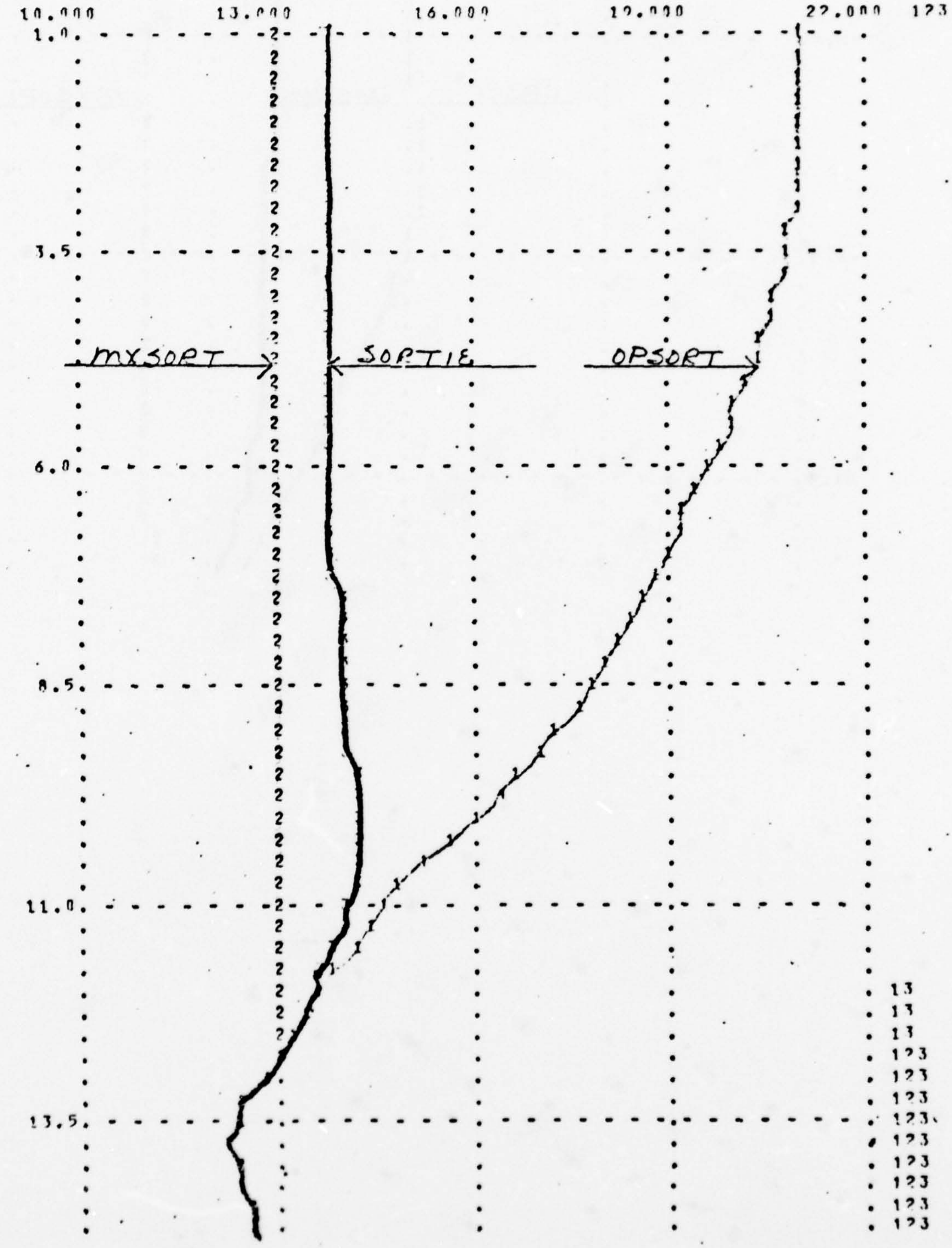
16.0
18.5
21.0
23.5
26.0
28.5
OPSORL
MXSORL
DESHRS

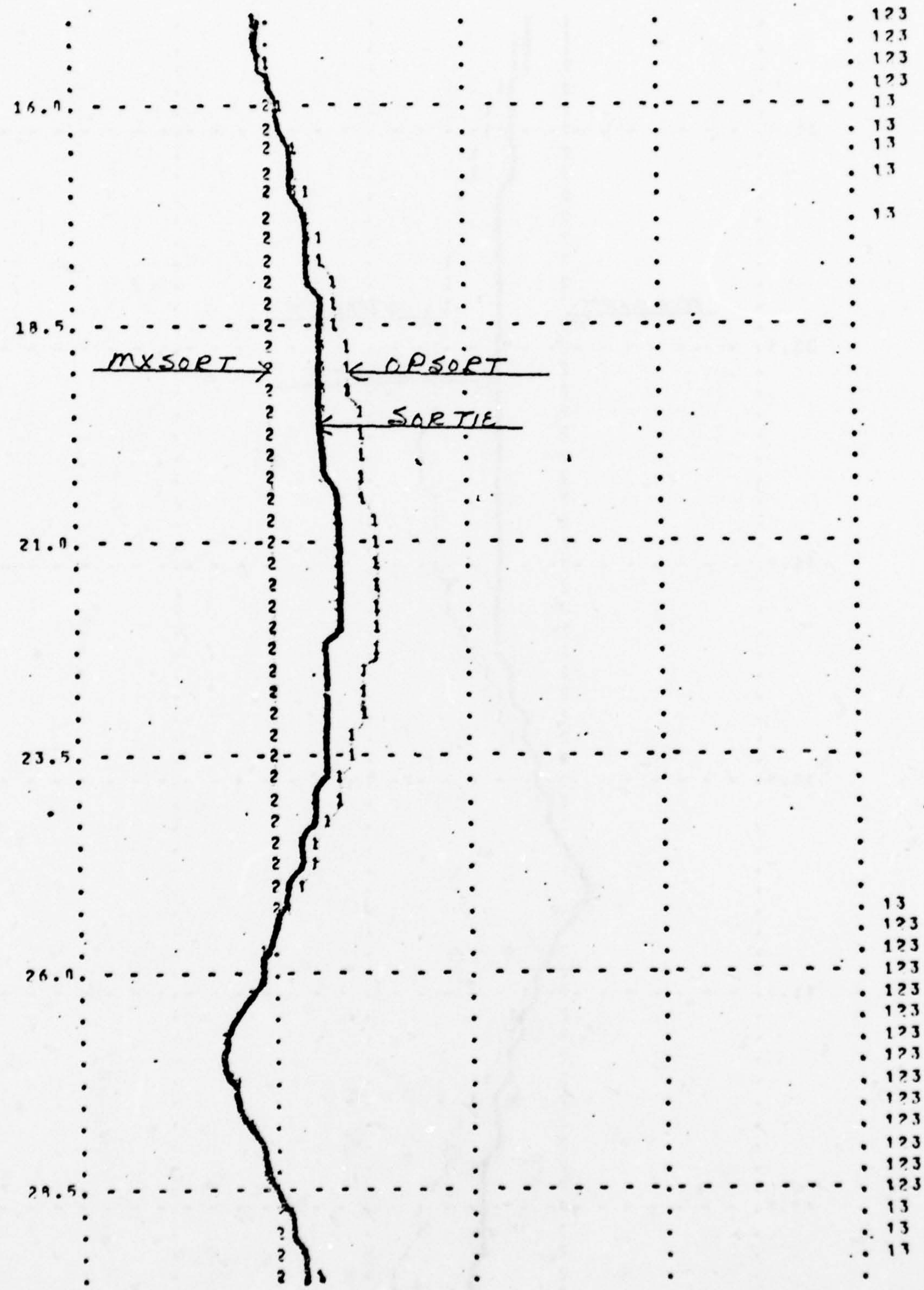

31.0
33.5
36.0
38.5
41.0
43.5
OPSORL
DESHPS
MXSORL
13
13
123
123
123
123
123
13
13


46.0
48.5
51.0
OPSORL
DESHPS
MXSORL

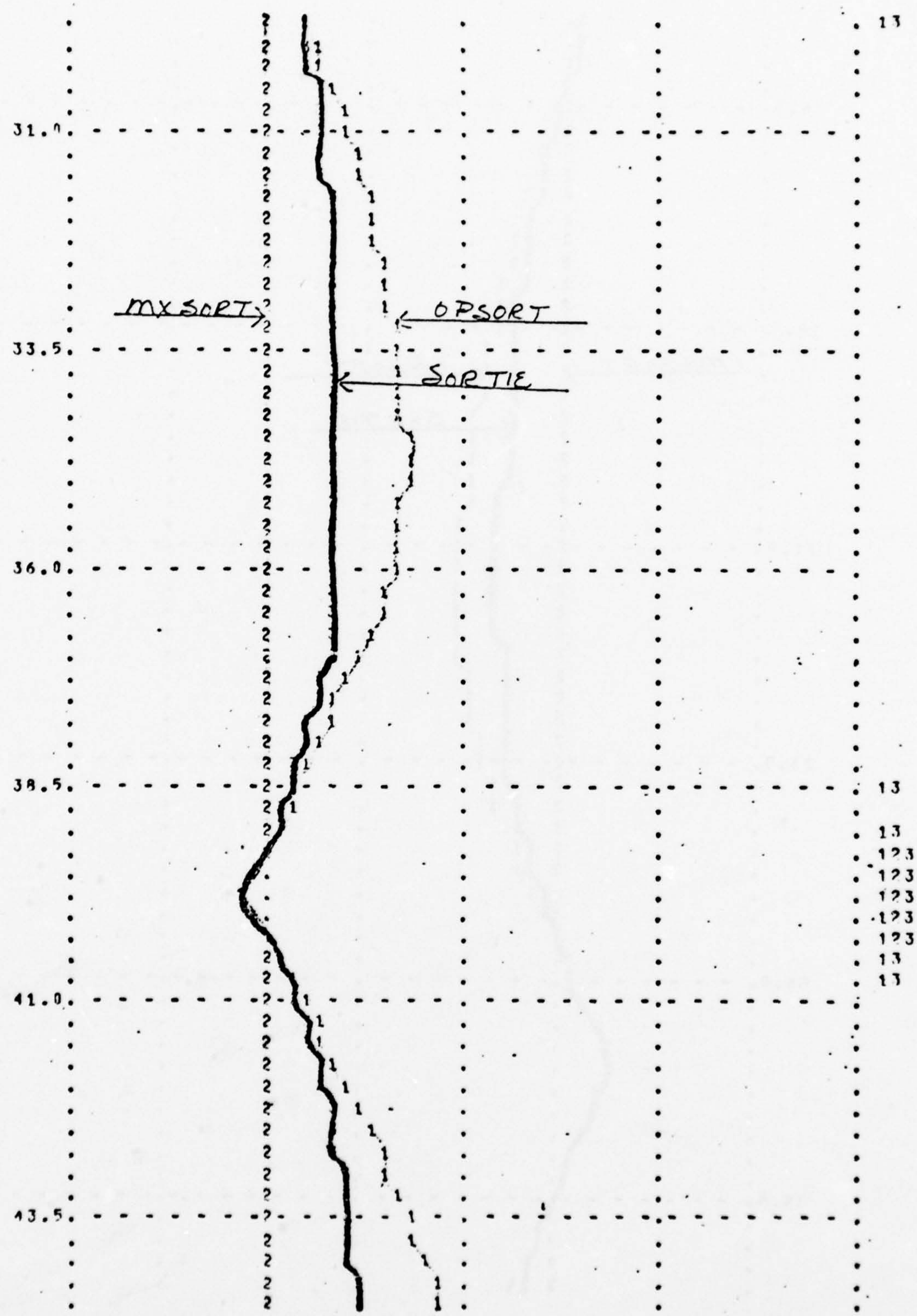
PAGE 15 WING LEVEL SCHEDULING--A SYSTEMIC MODEL BASIC

OPSORT=1 MXSORT=2 SORTIE=3

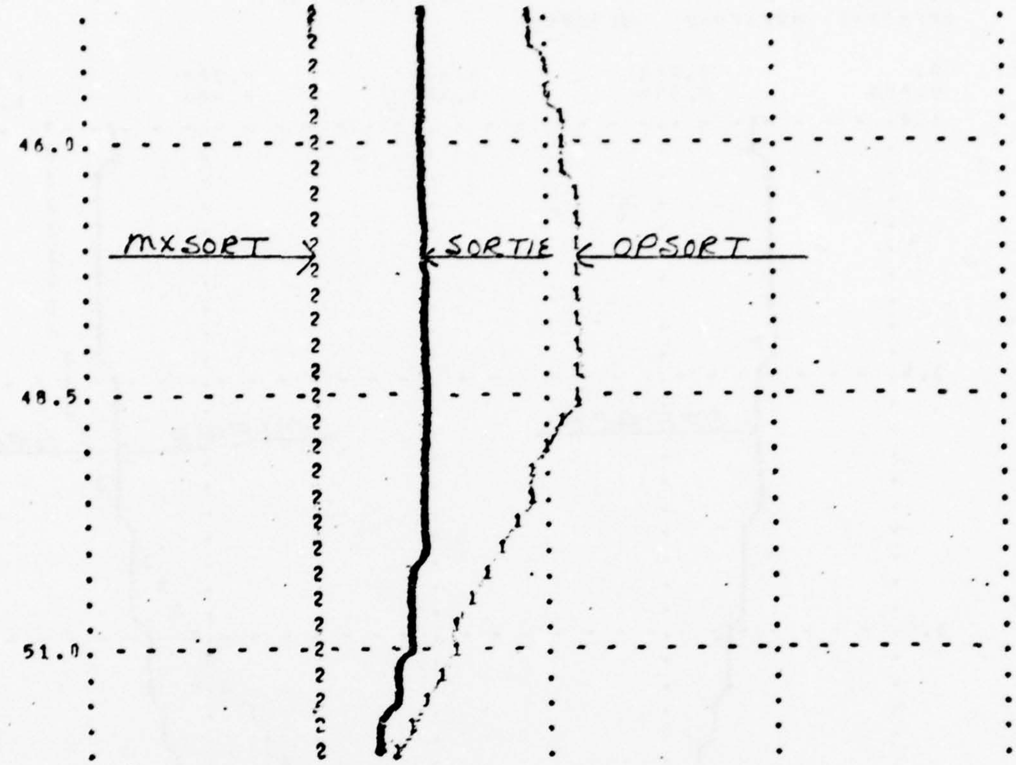




16.0
18.5
21.0
23.5
26.0
28.5
MXSORT
OPSORT
SORTIE

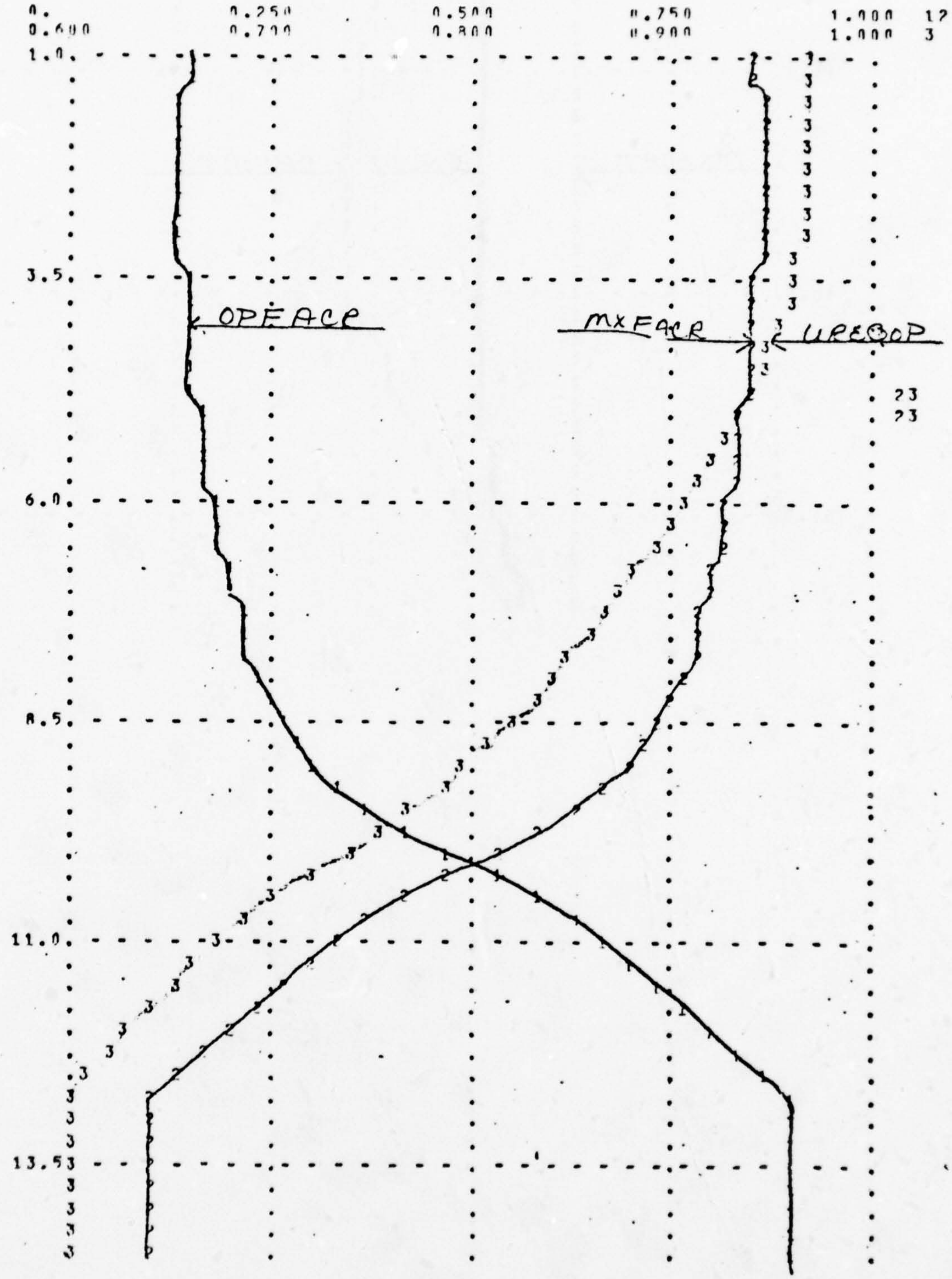


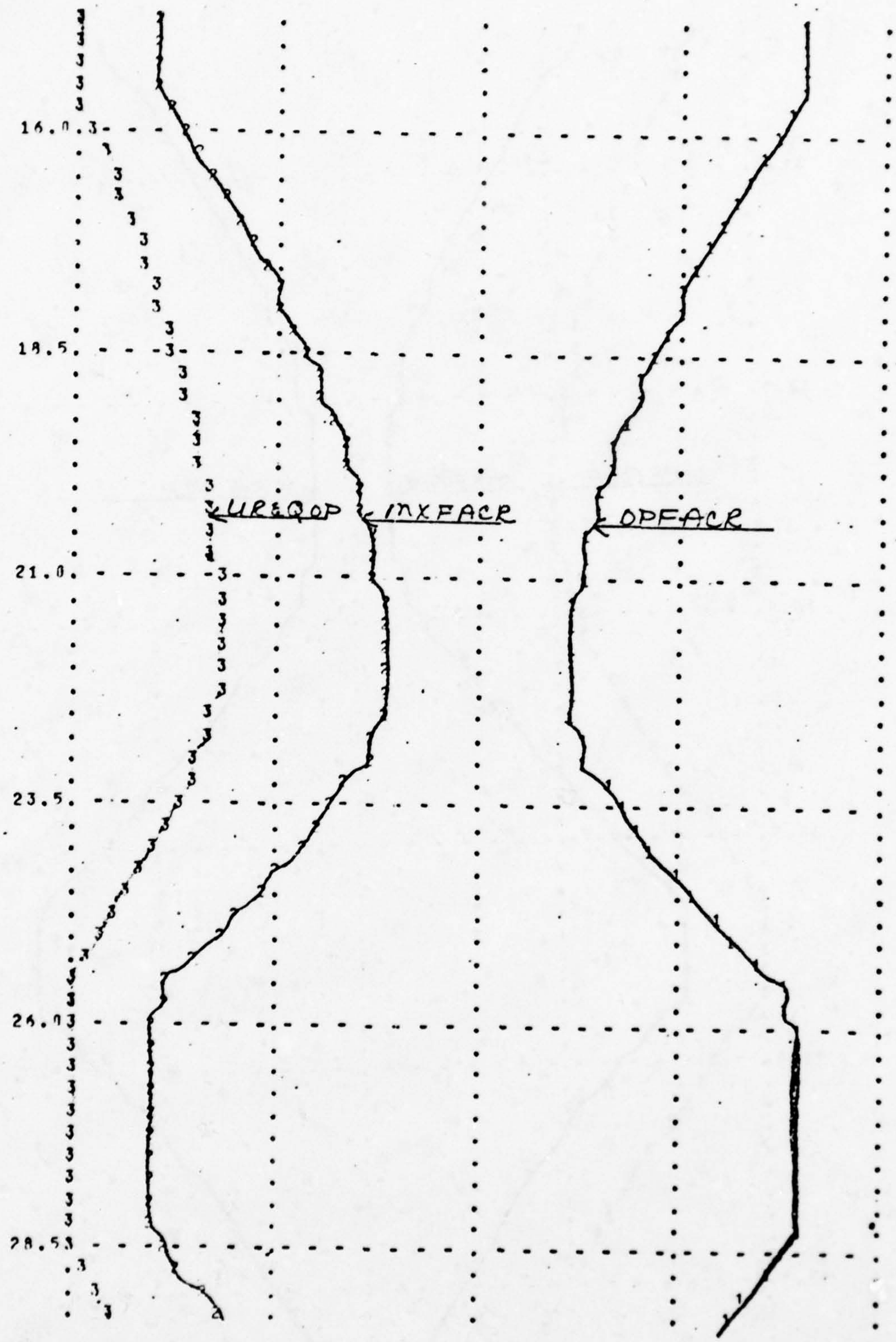
MXSORT
OPSORT
SORTIE
31.0
33.5
36.0
38.5
41.0
43.5

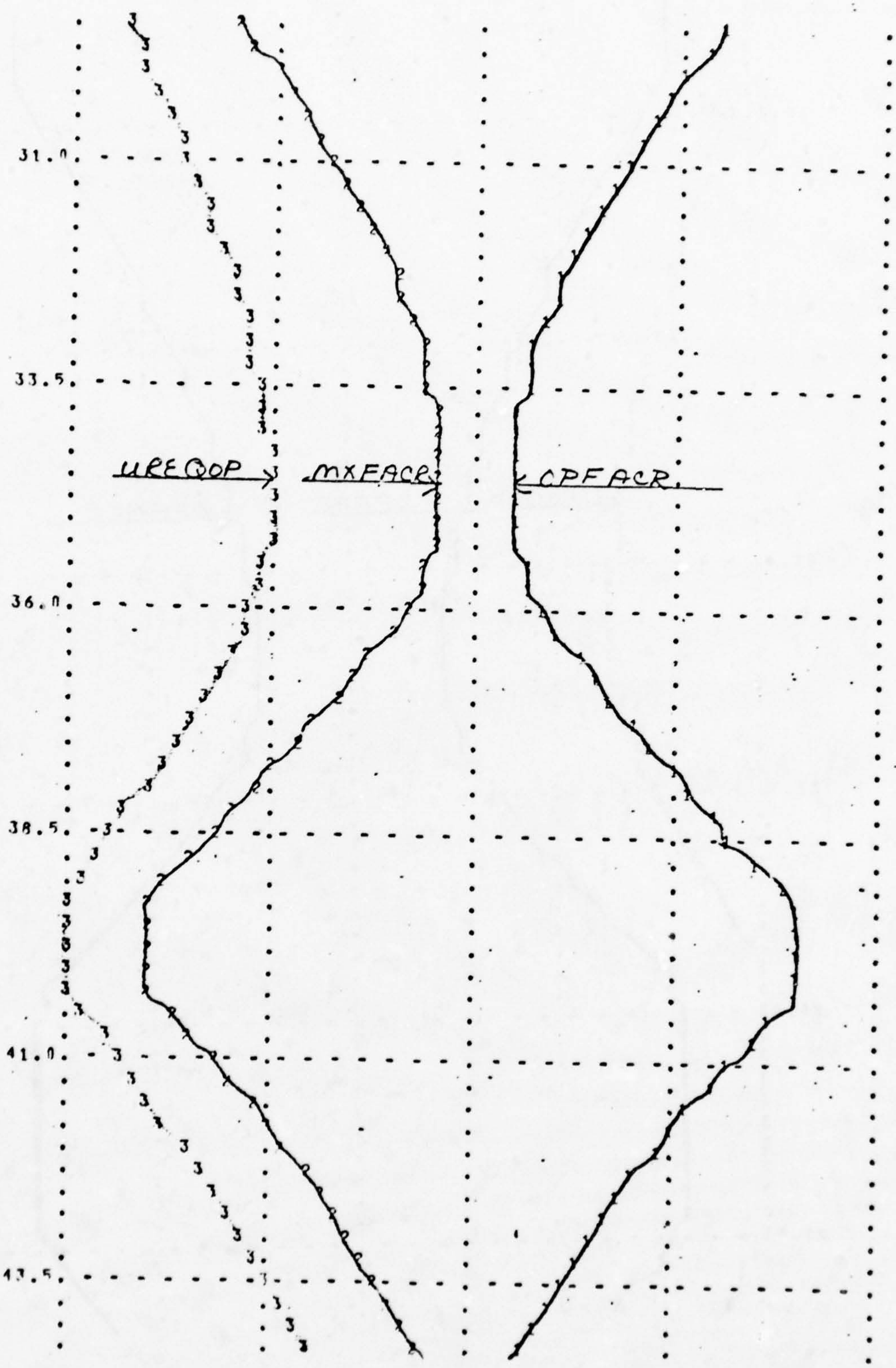


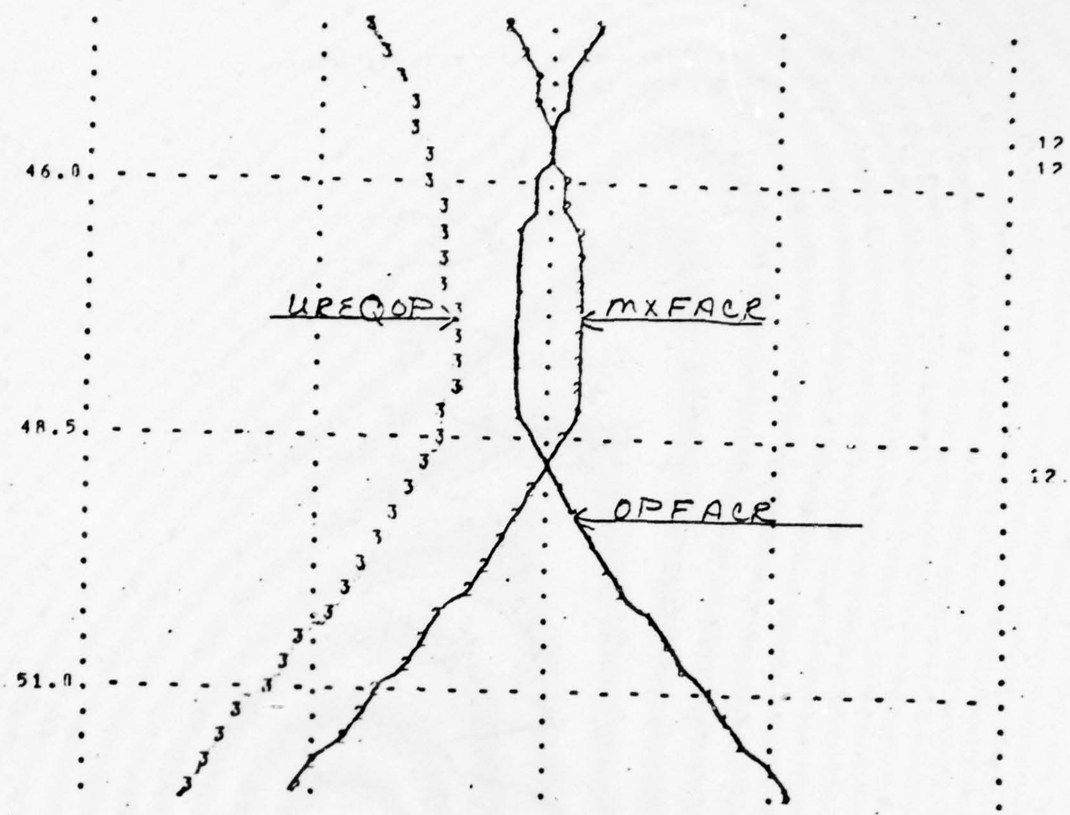
46.0
48.5
51.0
MXSORT
SORTIE
OPSORT

OPEACR=1 MXFACR=2 UREDOP=3



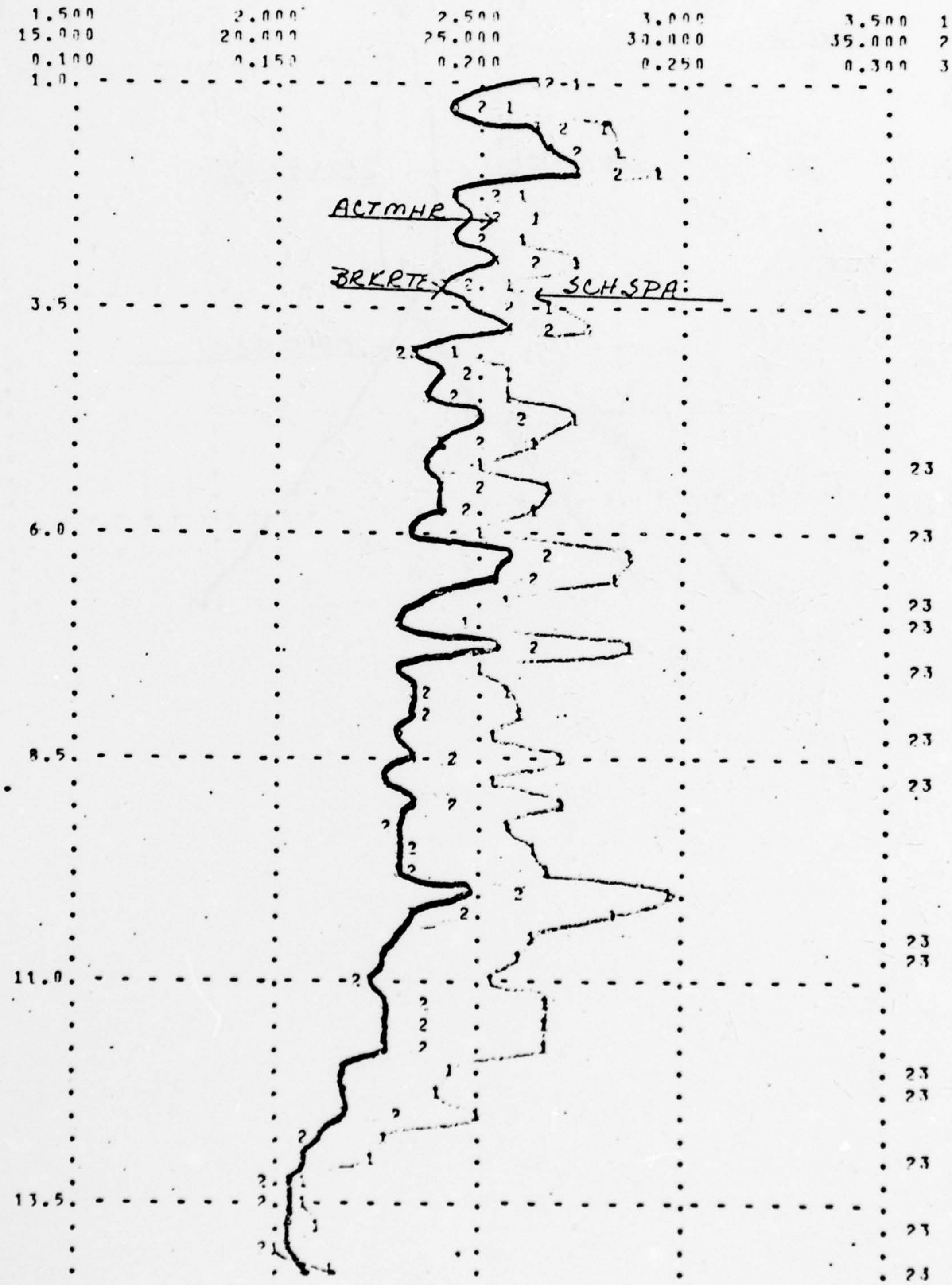

16.0
18.5
21.0
23.5
26.0
28.5
UREQOP
INXFACR
OPFACR

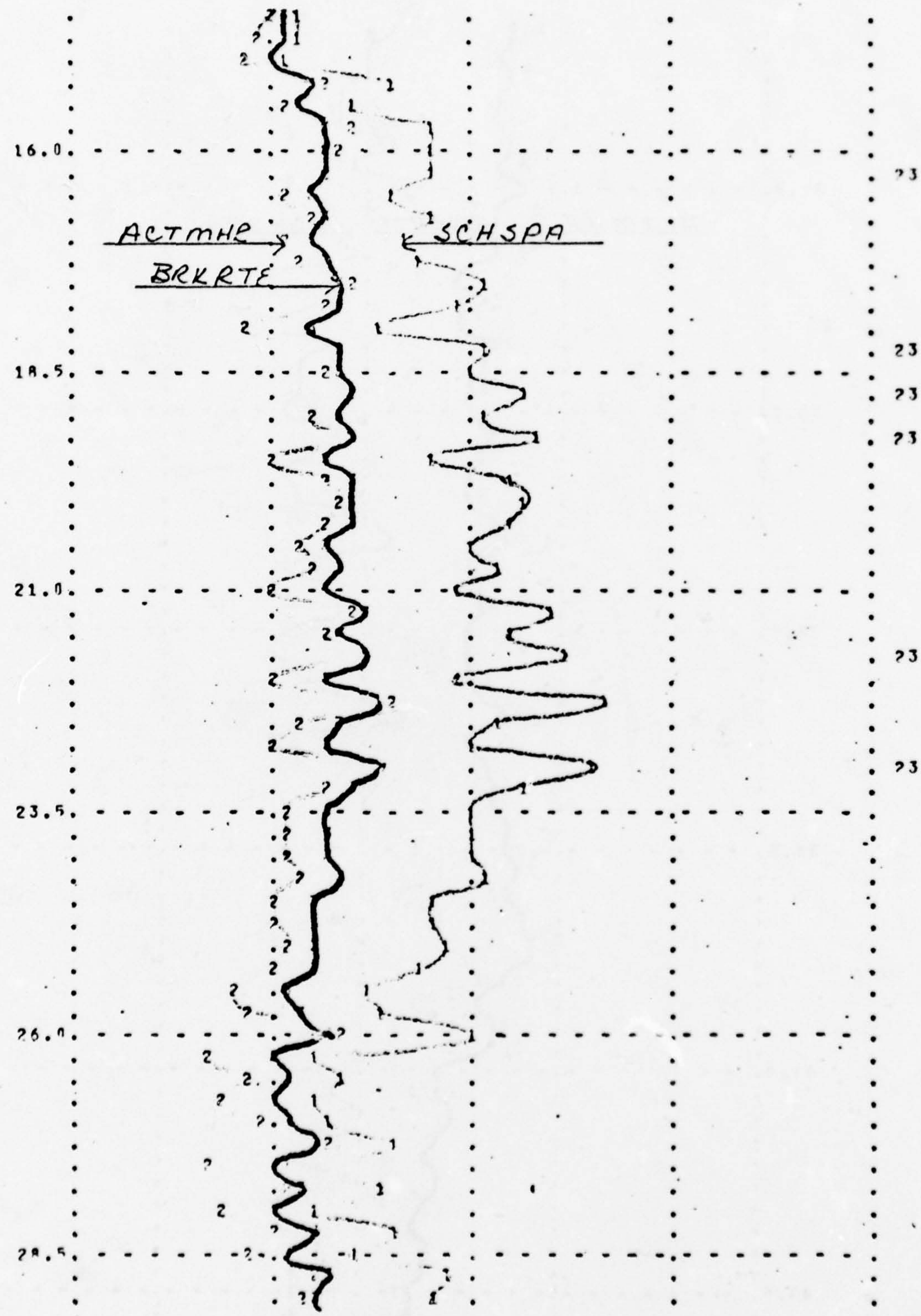

31.0
33.5
36.0
38.5
41.0
43.5
UREQOP
MXFACR
CPFACR

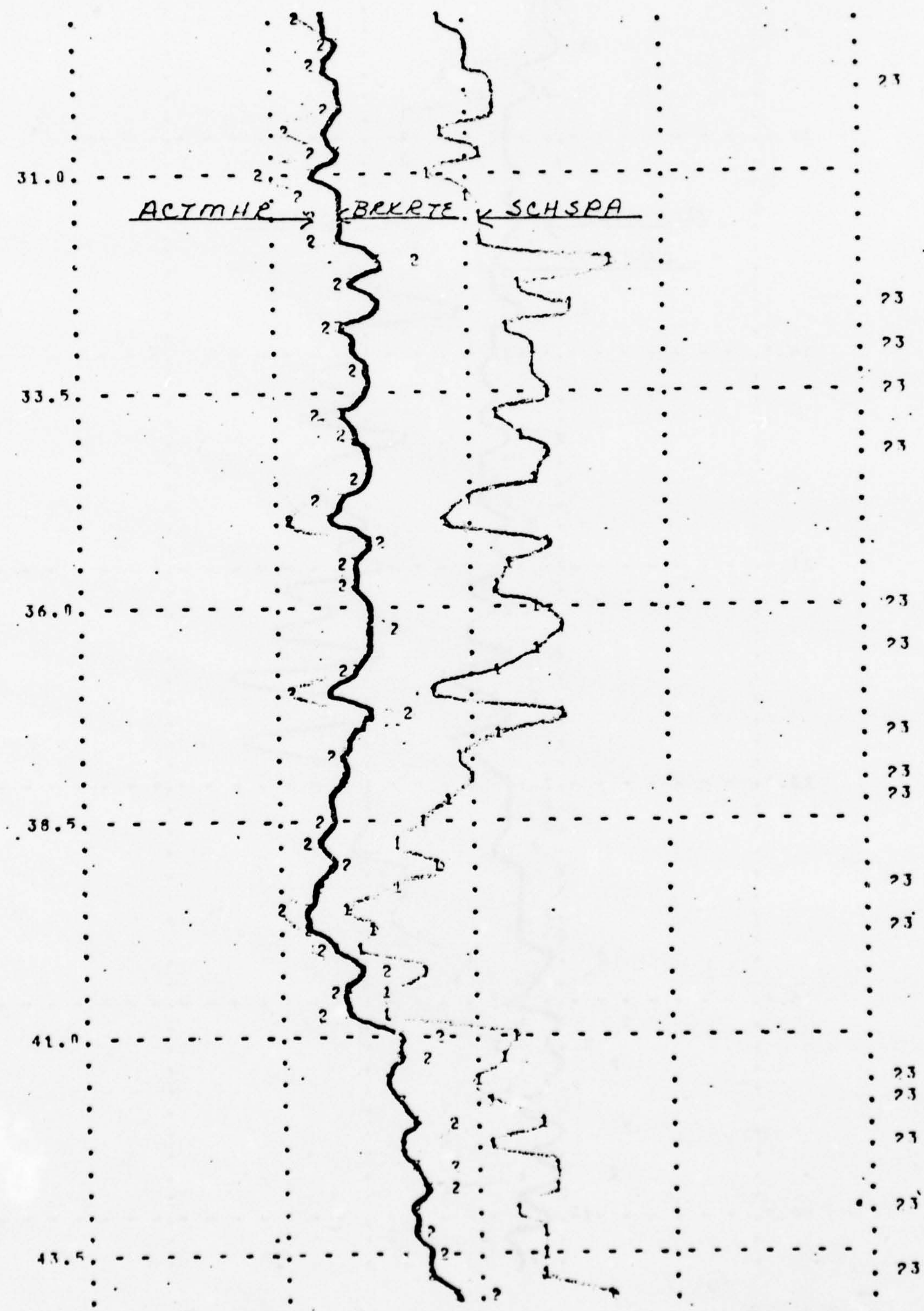


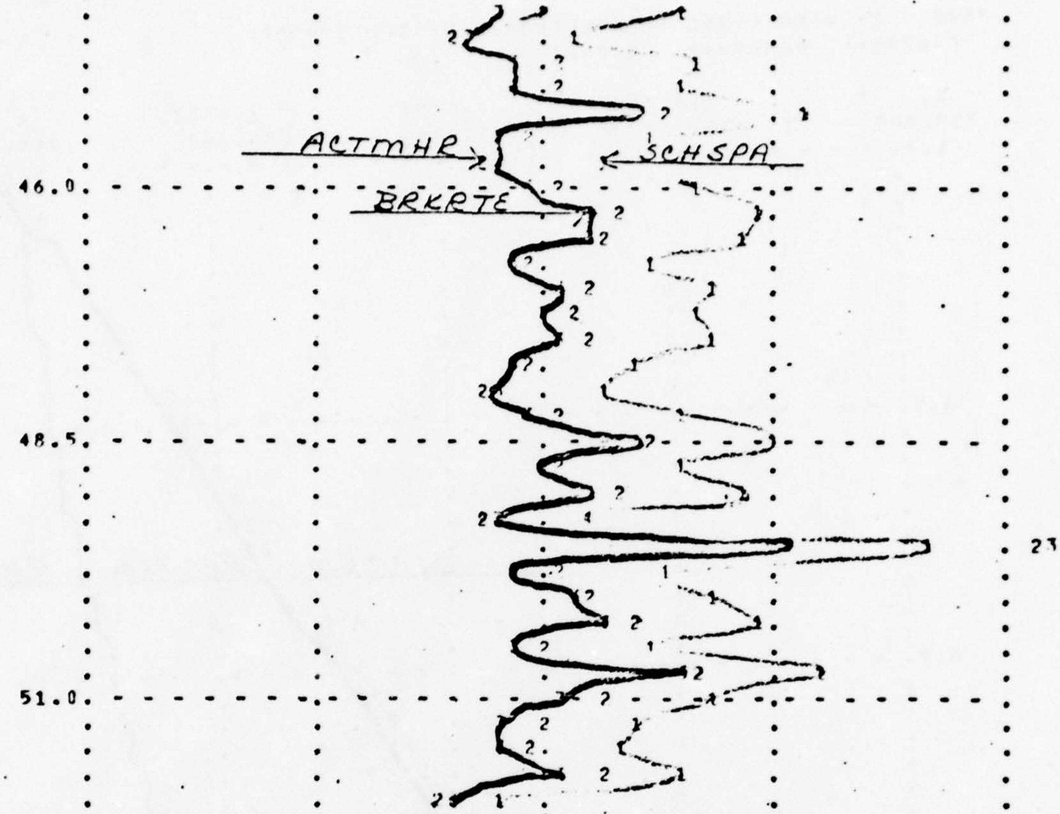
46.0
48.5
51.0
12
12
12
UREQOP
MXFACR
OPFACR

SCHSPA=1 ACTMHR=2 BRKRTE=3

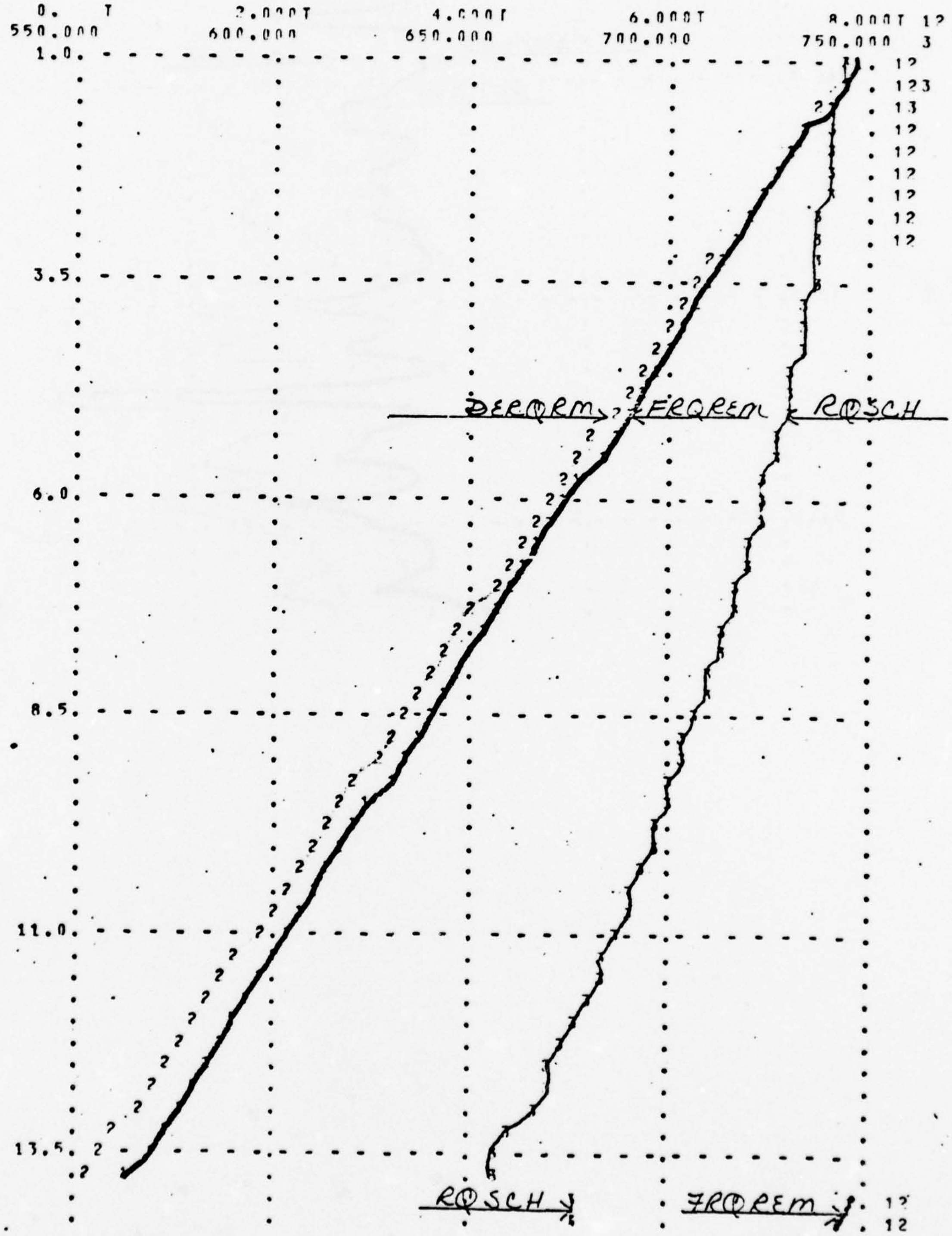


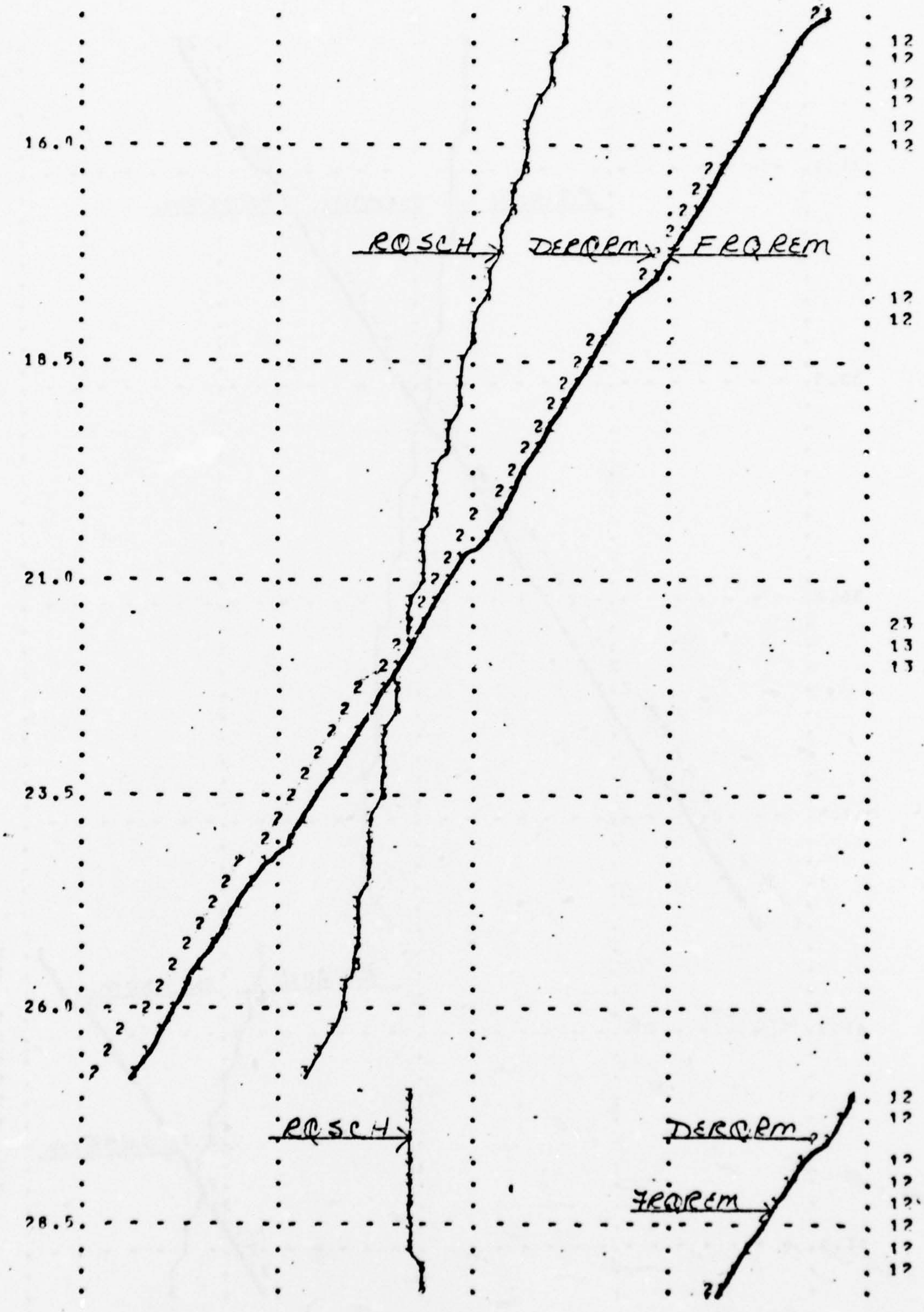

16.0
18.5
21.0
23.5
26.0
28.5
ACTMHP
BRKRTE
SCHSPA
23
23
23
23
23
23


31.0
ACTMHR
BRKRTE
SCHSPA
33.5
36.0
38.5
41.0
43.5

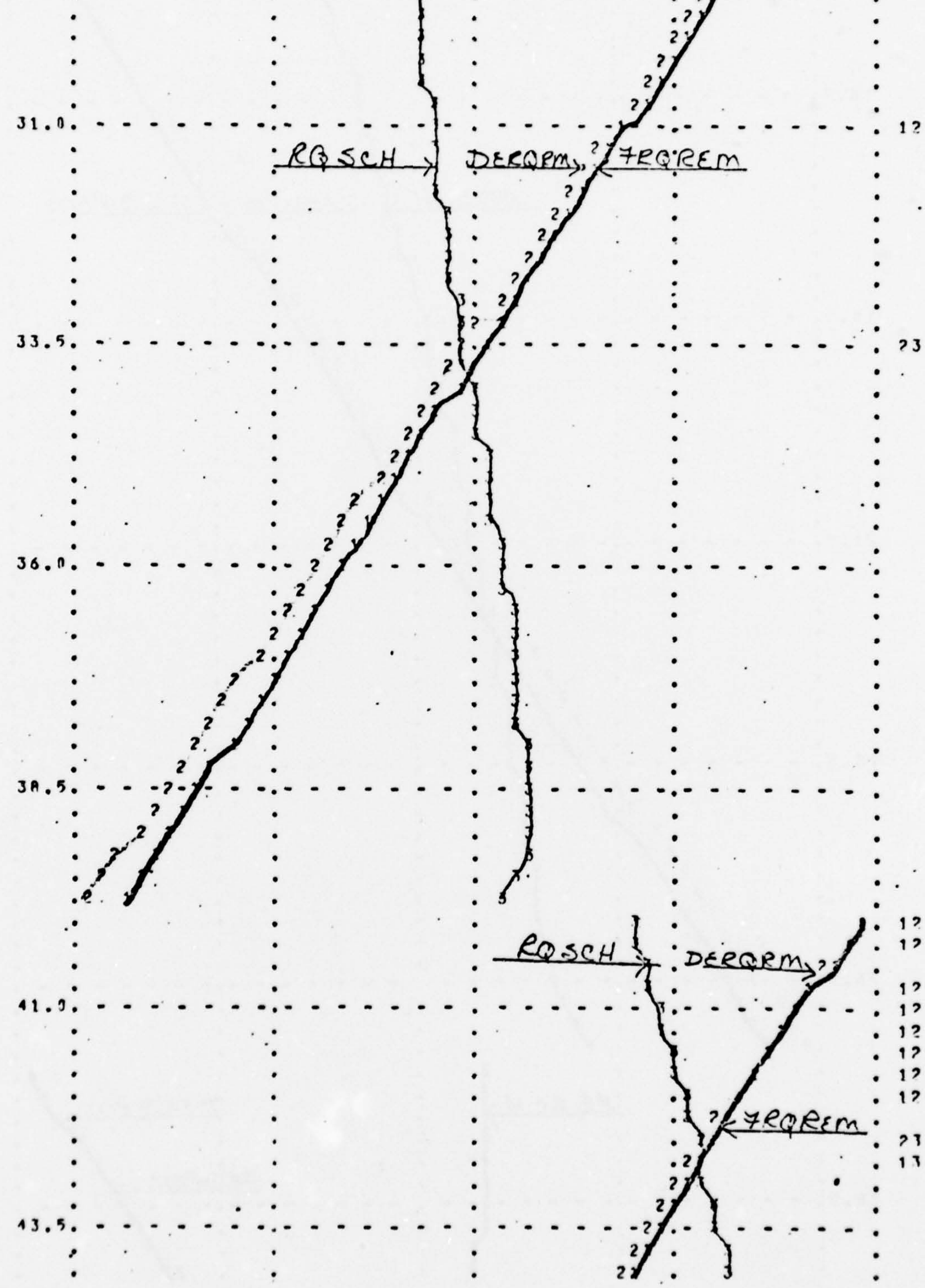

ACTMHR
SCHSPA
BRKRTE
46.0
48.5
51.0
23

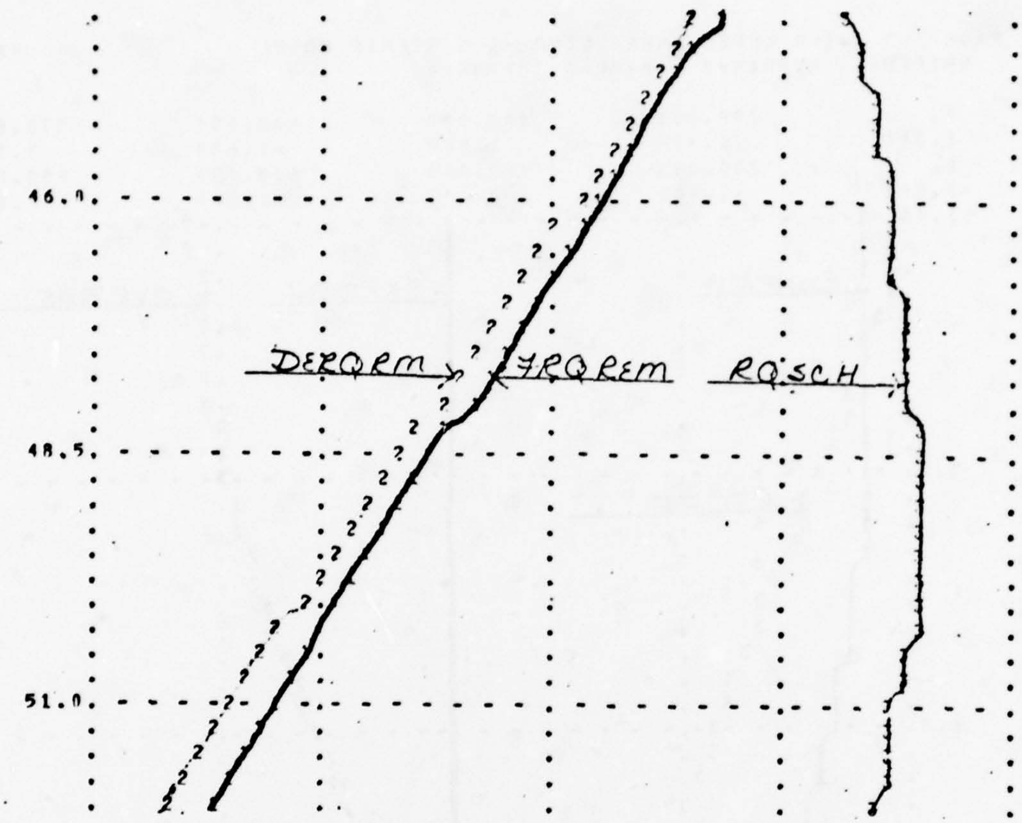
PAGE 1 WING LEVEL SCHEDULING--A SYSTEMIC MODEL BASIC
FRQREM=1 DERQRM=2 RQSCH=3





16.0
18.5
21.0
23.5
26.0
28.5
RQSCH
DERQRM
FRQREM

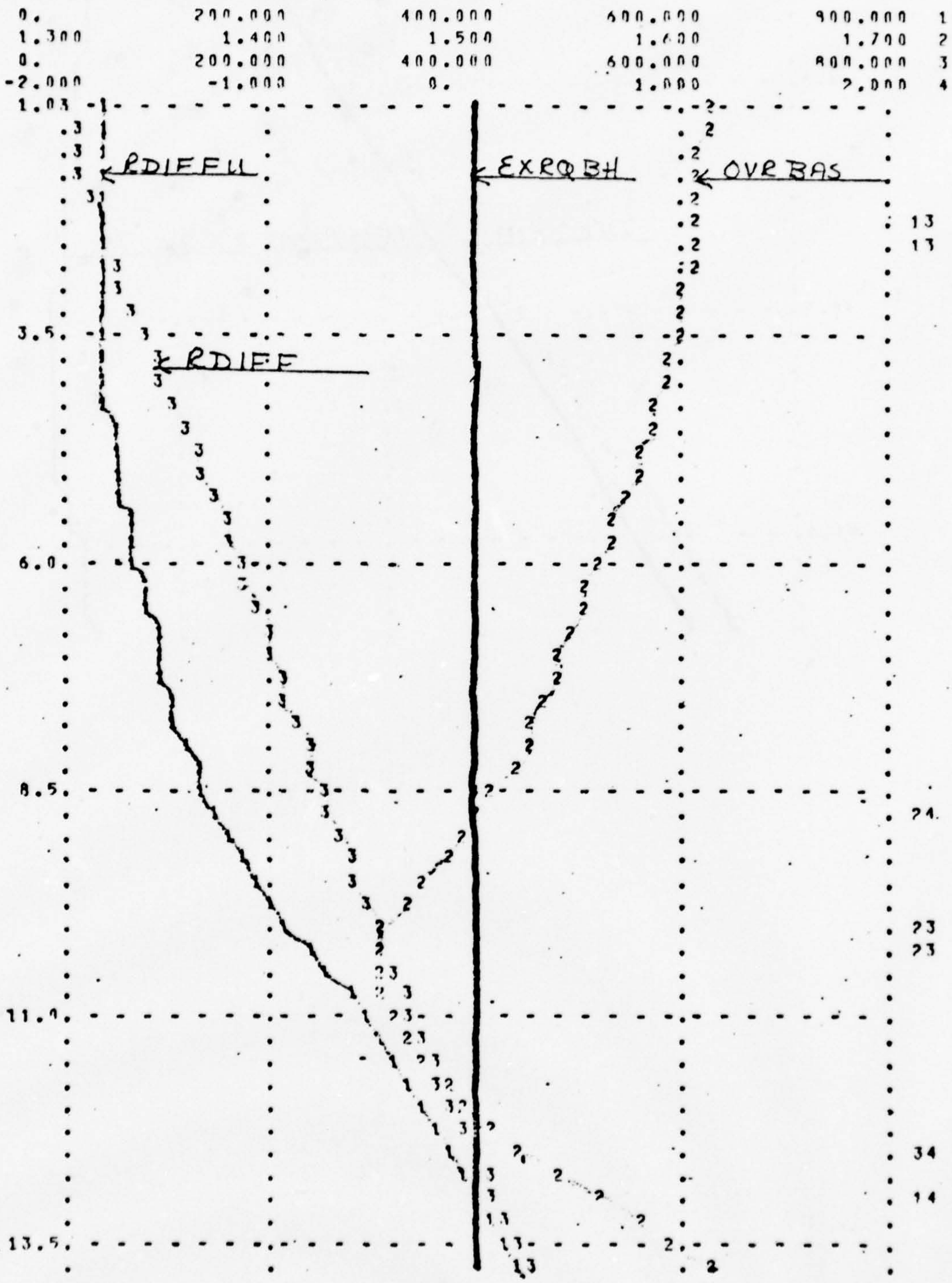

31.0
33.5
36.0
38.5
41.0
43.5
RQSCH
DERQRM
7RQREM
RQSCH
DERQRM
7RQREM

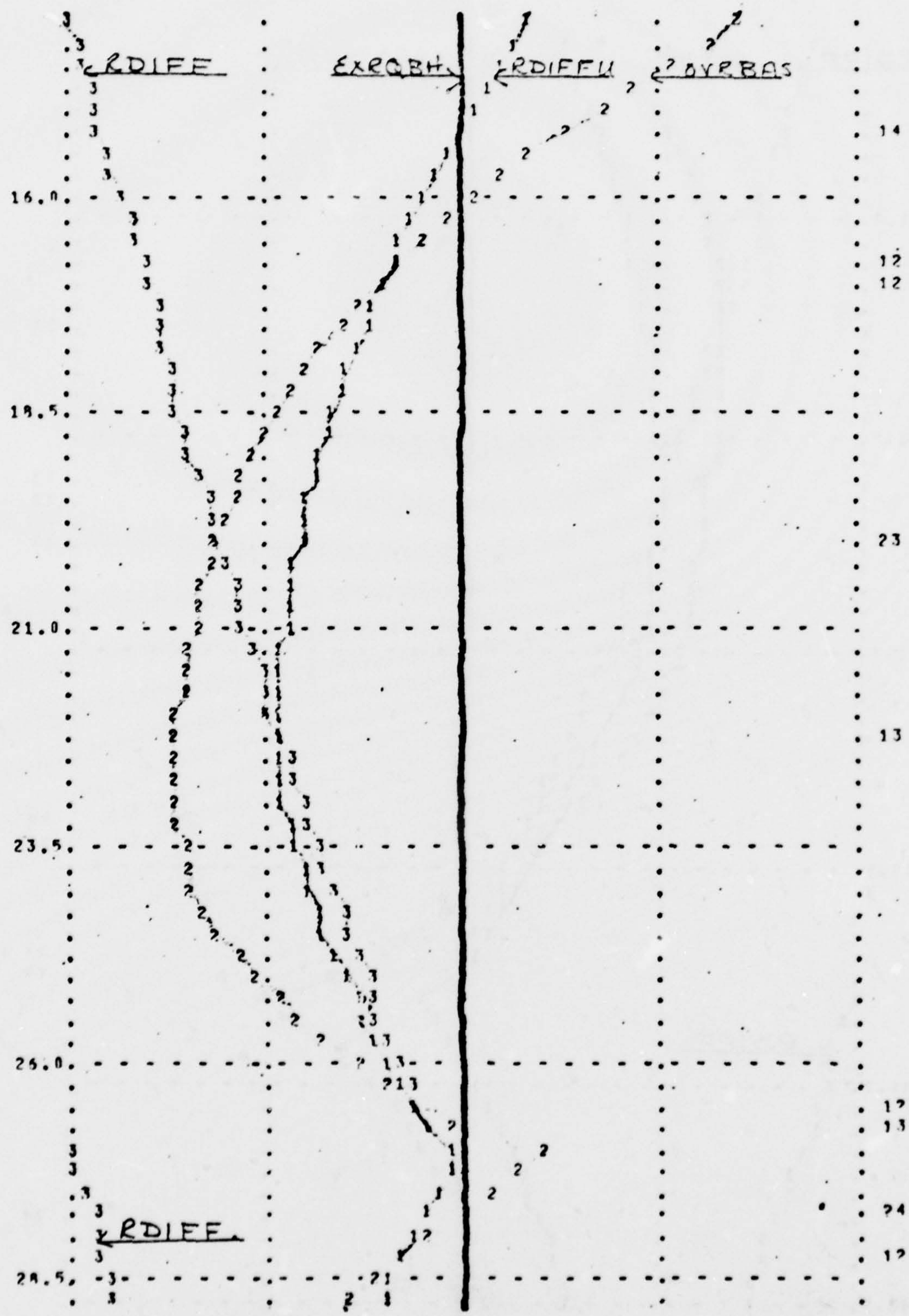


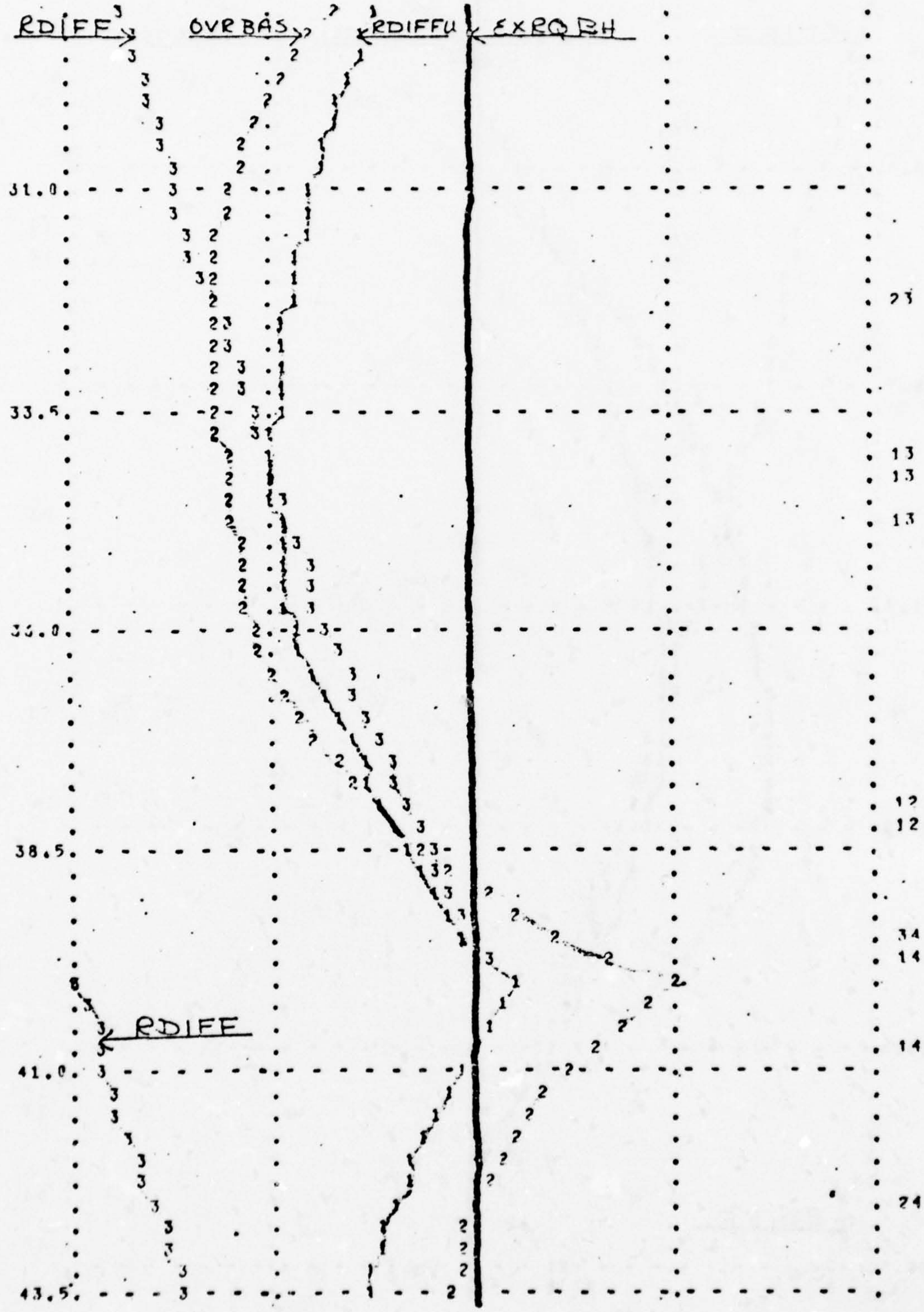
46.0
48.5
51.0
DERQRM
FRQREM
RQSCH

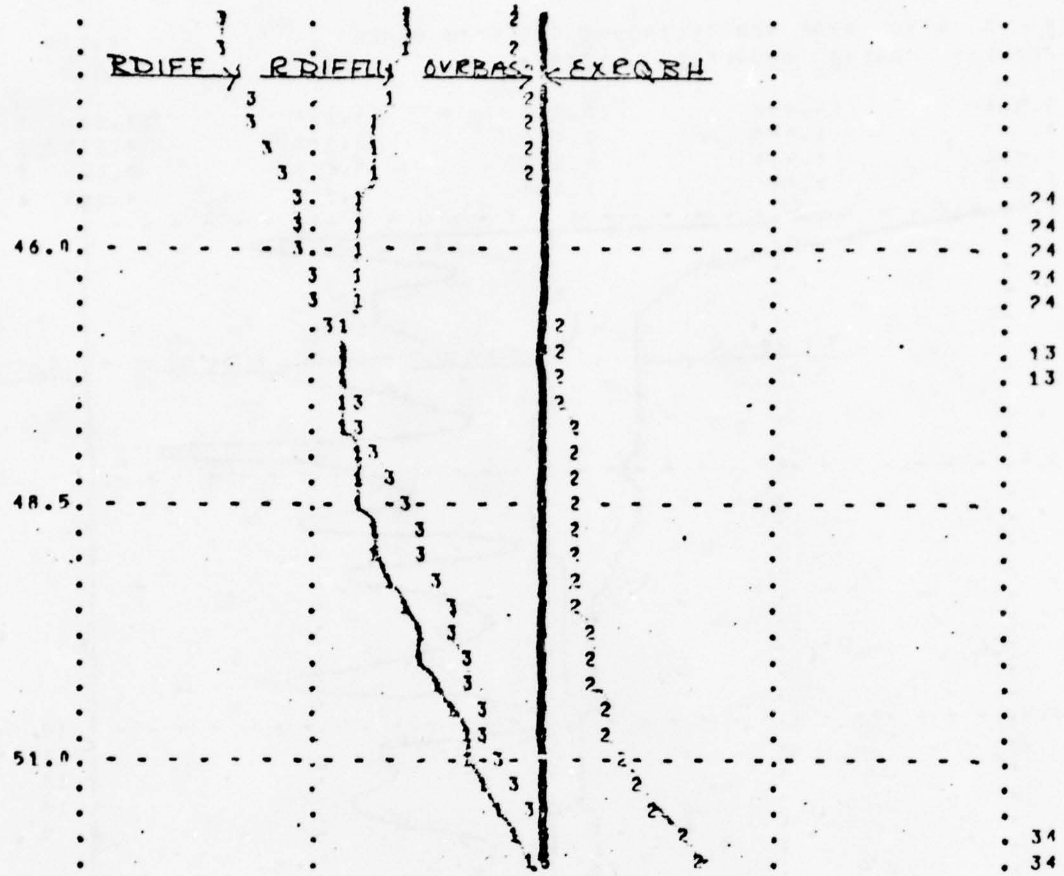
PAGE 2 WING LEVEL SCHEDULING--A SYSTEMIC MODEL BASIC

RDIFFU=1 OVRBAS=2 RDIFF=3 EXRQBH=4




RDIFF
EXRQBH
RDIFFU
DYRBAS
16.0
18.5
21.0
23.5
26.0
28.5
RDIFF

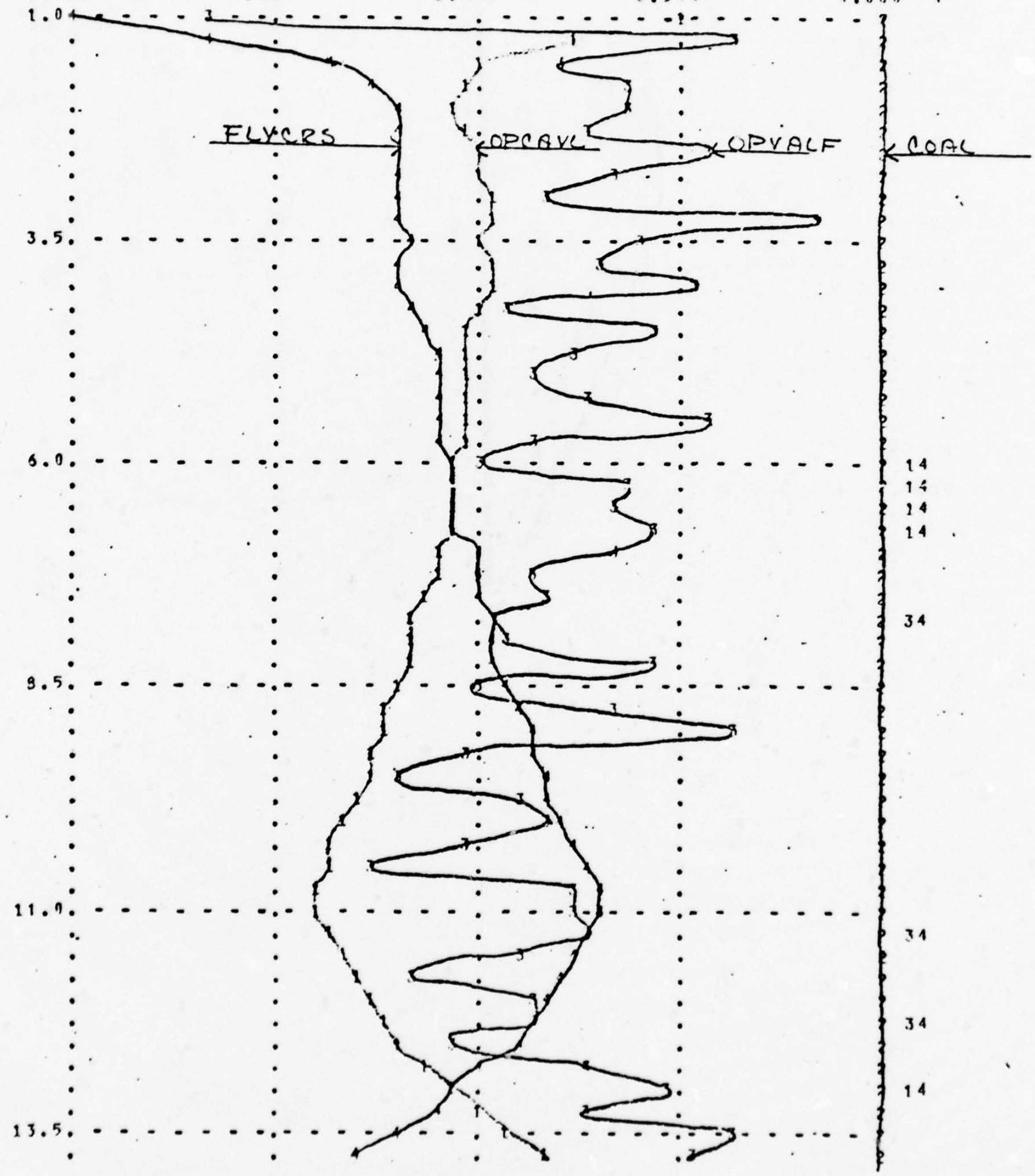

RDIFF
OVRBAS
RDIFFU
EXRQRH
31.0
33.5
38.5
41.0
43.5
RDIFF

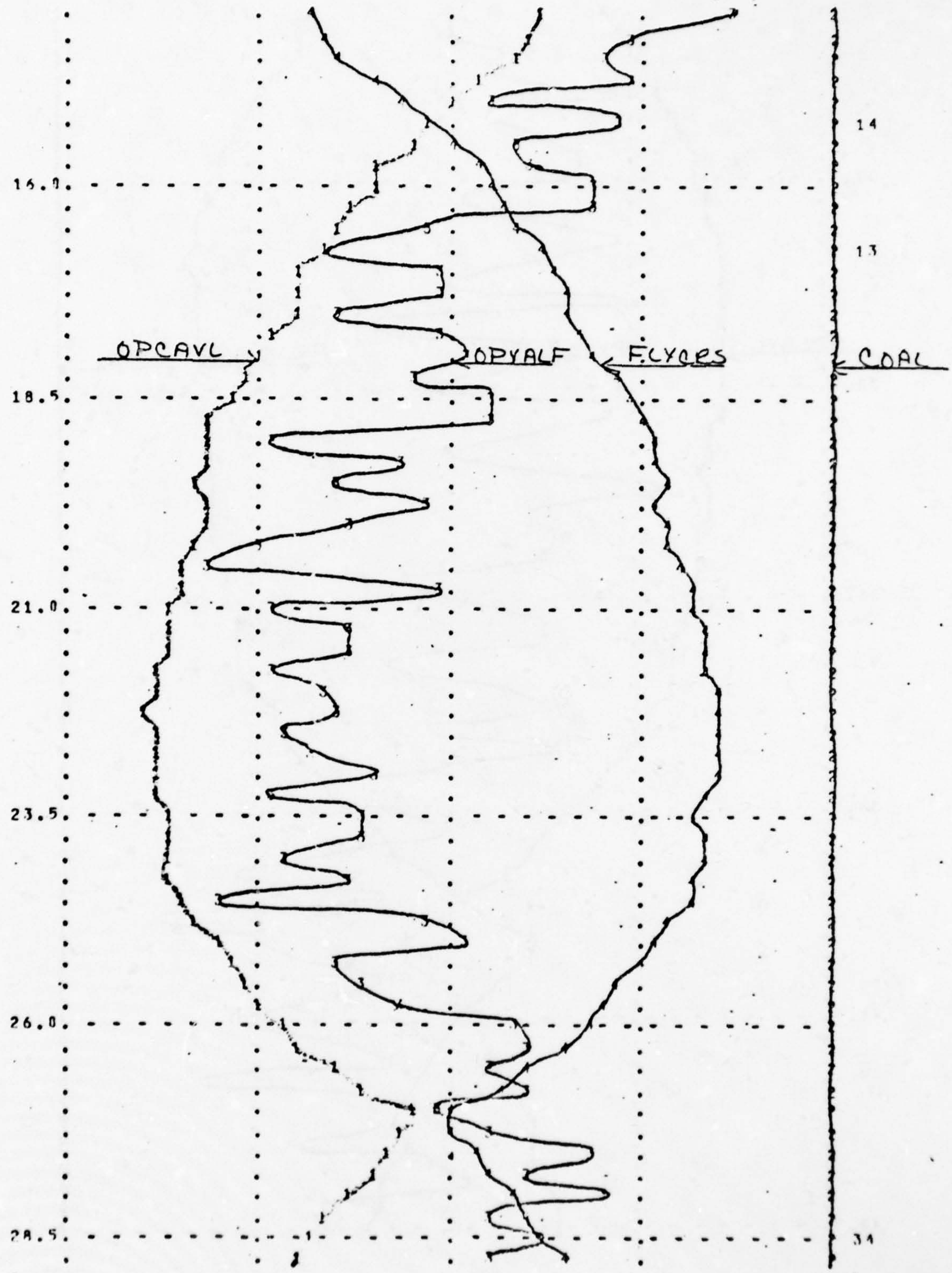

RDIFF
RDIFFL
OVRBAS
EXPQBH
46.0
48.5
51.0

PAGE 3 WING LEVEL SCHEDULING--A SYSTEMIC MODEL BASIC

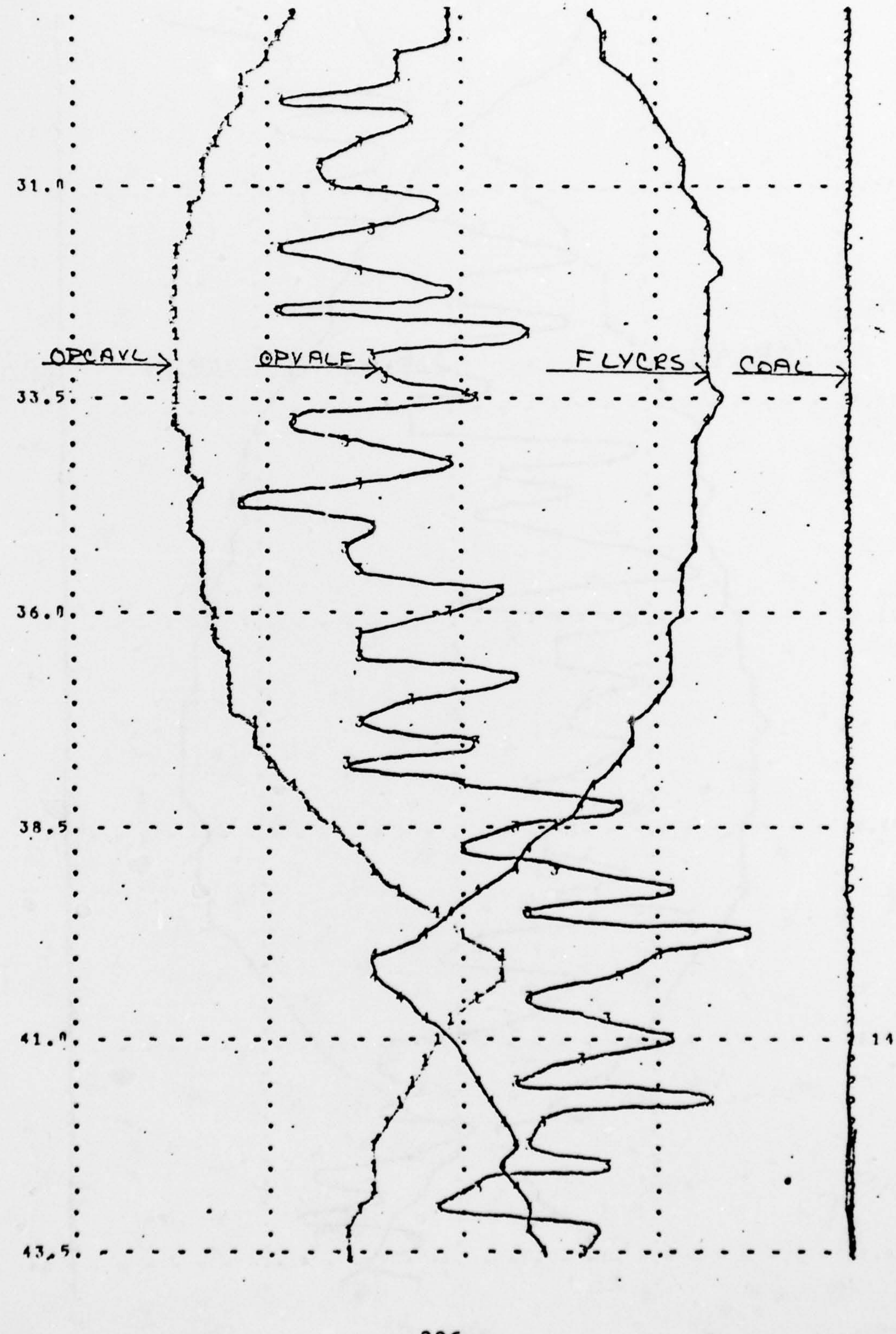
OPCAVL=1 COAL=2 OPAVLF=3 FLYCRS=4

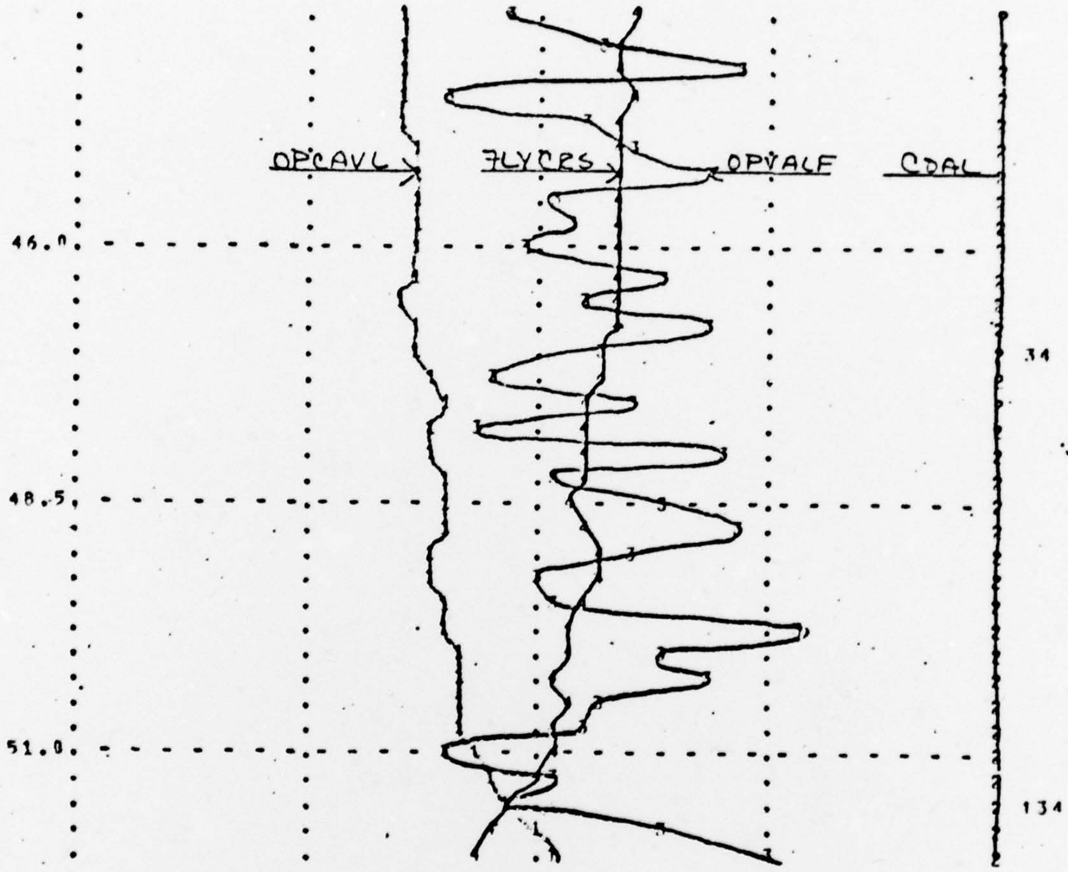
9.500	10.000	10.500	11.000	11.500	1
0.	1.000	2.000	3.000	4.000	2
7.000	7.500	8.000	8.500	9.000	3
2.000	2.500	3.000	3.500	4.000	4





16.0
18.5
21.0
23.5
26.0
28.5
OPCAVL
OPYALF
F.CYCRS
COAL
14
13


31.0
33.5
36.0
38.5
41.0
43.5
OPCAVC
OPVALF
FLYCRS
COAL
11


OPCAVL
7LYCRS
OPVALF
CDAL
46.0
48.5
51.0
34
134

APPENDIX D

SYSTEM EQUATIONS FOR LORING AFB

```
10*     WING LEVEL SCHEDULING—A SYSTEMIC MODEL
20NOTE     THIS MODEL IS BASED ON A 5 DAY WEEK
25NOTE
26NOTE
30NOTE     LINES CHANGED OR ADDED FOR LORING:
31NOTE     140,150,190,191,210,220,230,430
32NOTE     431,432,433,434,1040,1260,1360,
33NOTE     1410,1670,1780,1790,2070,2100,
34NOTE     2130,2250,2620,2630
35NOTE
36NOTE
40NOTE     BEGIN FLY HRS RMN SECTOR
50NOTE
60N     HRSDES=133
80N     HRSFLN=80
90N     HRUSRT=80
100N     WKSREM=13
110N     HRLRTC=.12
120N     TIME=1
130N     HRSASG=0
140N     FHRRMN=1358
150C     FLYALC=1266
160A     HRSASG.K=PULSE(FLYALC,13.99,13)
170L     FHRRMN.K=MAX((CLIP((FHRRMN.J+HRSASG.J-
171X     (DT*HRUSRT.JK)),
180X     ALLOC.J,ALLOC.J,(FHRRMN.J+HRSASG.J-
181X     (DT*HRUSRT.JK)))),0)
190A     RX.K=RAMP(CUR.K,0)
191A     CUR.K=-104.4615385+STEP(7.0769232,14)
200A     DIFF.K=MAX((FHRRMN.K-DEHRMN.K),0)
210A     DEHRMN.K=(1358+STEP(FLYALC,14))+RX.K
230A     ALLOC.K=1358-STEP(92,13.99)
240A     HRSDES.K=MAX(((FHRRMN.K/WKSREM.K)/
241X     (1-HRLRTC.K)-
250X     STEP(HRLOS,LOSWK)+STEP(HRGAIN.K,GAINWK)),0)
260C     HRLOS=0
270A     HRGAIN.K=HRLOS
280C     LOSWK=20
290C     GAINWK=21
300NOTE     LINES 202-205 REFLECT STAND DOWN
301NOTE     STAND DOWN IS USED TO AID MAINT
310A     HRLRTC.K=HRLRTP+A*COS(2*PI*(TIME.K-DT)/P)
320C     PI=3.14
330C     P=52
340C     A=.07
350C     HRLRTP=.12
360C     WKCLOS=0    FAC TO MULT HRLRTR BY
370C     STALOS=16    START INCREASED WEEKLY LOSS
```

```
380C    STPLOS=17    STOP INCREASED WEEKLY LOSS
390A    WKCLO.K=WKCLOS
400A    WKLOS.K=1+STEP(WKCLOS,STALOS)
401X    -STEP(WKCLO.K,STPLOS)
410A    WKSREM.K=X.K-(TIME.K)
420A    X.K=14+STEP(13,14)+STEP(13,27)+STEP(13,40)
430A    HRLRTR.K=TABHL(LORLOS,TIME.K,1,26,1)*WKLOS.K
431T    LORLOS=.038/.418/.345/.111/.038/.174/.096
432X    /.08/.255/.015/.187/.334/0/.114/.125/.045
433X    /.037/.035/.198/.037/.109/.129/.051/
434X    .030/.042/0
450A    HRSSNA.K=ACSCHF.K*HRLRTR.K*ACTMHR.K
460A    OVRRTR.K=MAX((NORMRN(.01,.005)),0)
470A    HRSOVR.K=OVRRTR.K*ACSCHF.K*ACTMHR.K
480A    HRSPOS.K=HRSACT.K-HRSSNA.K+HRSOVR.K
490A    HRSFLN.K=SORTFL.K*DESHRS.K
500R    HRUSRT.KL=HRSFLN.K
510NOTE
520NOTE    END FLY HRS REMAIN SECTOR
530NOTE
540NOTE    BEGIN AC AVAIL SECTOR
550NOTE
560NOTE    THIS MODEL ASSUMES 15 AIRCRAFT ON STATION
570NOTE
575N    HRSPO=80
580N    ACAVAL=8
590N    ACON=4
600N    ALRTAC=1
610N    INMX=3
620N    NOFLAC=0
630N    FLYAC=0
640N    ACRQMX=2
650N    ACSNAF=.5
660N    SCHACF=3
670N    MXFACT=.14
680N    MXGEN=.14
690N    BRKRT1=.1
700N    BRKRT2=.2
710N    BRKRT3=.3
720N    BRKRTE=.2
730C    ALRTRQ=4    ALERT REQUIREMENT
740C    DEMX=1
750C    DEALRT=4.6
760A    DEACFL.K=TABHL(DEACF,ACTSPA.K,0,15,1)
761T    DEACF=.2/.2/.4/.6/.8/1/1.2/1.4/1.6/
762X    1.8/2.0/2.2/2.4/2.6/2.8/3.0
770A    DEACNF.K=.158
780C    DESORT=1    DESIRED SORTIES PER AC PER WEEK
```

```
790L    ACAVAL.K=MAX((ACAVAL.J+(DT)*(RQMXAC.JK+
791X    ALRTAC.JK+ACSNA.JK+ACFLAC.JK
800X    -ACRQMX.JK-ACONA.JK-ACSNAF.JK-SCHACF.JK)),Ø)
810L    INMX.K=INMX.J+(DT)(ACRQMX.JK-RQMXAC.JK)
820R    ACRQMX.KL=MIN((MXFACT.K*EXCMNT.K*ACAVAL.K),
821X    (ACAVAL.K-ACONA.JK))
830A    EXCMNT.K=1+STEP(EXLOSS,MXLOSS)-
831X    STEP(EXLOS.K,MXGAIN)
840A    EXLOS.K=EXLOSS
850C    EXLOSS=Ø    FAC TO MULT ACRQMX BY
860C    MXLOSS=17    START WEEK FOR INCR MAINT
870C    MXGAIN=18    STOP WEEK FOR INCR MAINT
880A    MXFACT.K=MAX((MIN(MXGEN.K,.75)),.1)
890A    BRKRT1.K=TABHL(BRKR1,ACTMHR.K,20,45,5)
900T    BRKR1=.1/.1/.2/.3/.4/.5
910A    BRKRT2.K=TABHL(BRKR2,SCHSPA.K,1,5,1)
920T    BRKR2=.1/.2/.3/.45/.6
930A    BRKRT3.K=TABHL(BRKR3,HRSACT.K,Ø,280,4Ø)
940T    BRKR3=Ø/.1/.1/.15/.35/.45/.5/.55
950A    BRKRTE.K=(BRKRT1.K+BRKRT2.K+BRKRT3.K)/3
960A    MXGEN.K=NORMRN(BRKRTE.K,(BRKRTE.K/6))
970R    RQMXAC.KL=DELAY1(ACRQMX.JK,DEMX)
980A    ACAVLA.K=MAX((ACAVAL.K-ACRQMX.JK),Ø)
990L    ACON.K=ACON.J+(DT)(ACONA.JK-ALRTAC.JK)
1000R    ACONA.KL=MIN((MIN((ALRTRQ-ACON.K+ALRTAC.JK)
1001X    ,ACAVLA.K)),OPALRT.K)
1010R    ALRTAC.KL=DELAY3(ACONA.JK,DEALRT)
1020A    ACAVLF.K=MAX((ACAVAL.K-ACONA.JK-ACRQMX.JK)
1021X    ,Ø)
1030A    MAXHR.K=CLIP(Ø,(MIN((HRSDES.K/((ACAVLF.K)+
1031X    (1E-2Ø))),45)),Ø,ACAVLF.K)
1040A    EXRQHB.K=TABHL(EXRQH,EXRQBH.K,Ø,760,152)
1050T    EXRQH=Ø/35/70/105/140/175
1060A    MAXHRS.K=CLIP(Ø,(MIN((MAXHR.K+((EXRQHB.K/
1061X    ((ACAVLF.K)+(1E-2Ø))))*2)),
1070X    45)),Ø,ACAVLF.K)
1080A    HRAVLF.K=MAX((ACAVLF.K*MAXHRS.K),Ø)
1090A    HRSPO.K=MIN(HRSDES.K,HRAVLF.K)
1100A    ACSCHF.K=MIN((SORTIE.K/DESORT),ACAVLF.K)
1110A    ACTMHR.K=CLIP(Ø,(HRSACT.K/((ACSCHF.K)+
1111X    (1E-2Ø))),Ø,ACSCHF.K)
1120A    SCHSPA.K=CLIP(Ø,(SORTIE.K/((ACSCHF.K)+
1121X    (1E-2Ø))),Ø,ACSCHF.K)
1130A    DNA.K=MAX((ACAVLF.K-ACSCHF.K),Ø)
1140L    NOFLAC.K=MAX((NOFLAC.J+(DT)(ACSNAF.JK-
1141X    ACSNA.JK)),Ø)
1150R    ACSNAF.KL=MAX((ACSCHF.K*HRLRTR.K),Ø)
1160R    ACSNA.KL=DELAY3(ACSNAF.JK,DEACNF.K)
```

```
1170L    FLYAC.K=MAX((FLYAC.J+(DT)(SCHACF.JK-
1171X    ACFLAC.JK)),Ø)
1180A    SCHAFL.K=ACSCHF.K-ACSCHF.K*HRLRTR.K
1190R    SCHACF.KL=SCHAFL.K
1200R    ACFLAC.KL=DELAY3(SCHACF.JK,DEACFL.K)
1210NOTE
1220NOTE    END AC AVAIL SECTOR
1230NOTE
1240NOTE    BEGIN OPS CREW AVAIL FOR FLY TNG SECTOR
1250NOTE
1260NOTE    THIS MODEL ASSUMES 15 CREWS ASSIGNED--
1270NOTE    2 CREWS ASSUMED ON LEAVE ATALL TIMES
1280NOTE
1290C    OCRASG=15
1300C    DEDNIA=1
1310C    DECALR=1.5
1320C    DECSCF=.44
1330C    DEOPNF=.44
1340C    EXDNIF=Ø    FAC TO MULT OPDNIF BY
1350A    EXDNI.K=EXDNIF
1360C    STADNF=20    WEEK TO START EXCESSIVE DNIF
1370C    STPDNF=21    WEEK TO STOP EXCESSIVE DNIF RATE
1380C    CRSORT=1    DESIRED SORTIES PER CREW PER WEEK
1390C    MNUTIL=.6
1391NOTE    60% UTIL.=13 SORTIES
1400NOTE    60% UTIL = .1 PRESS. FACTOR
1410N    OPCAVL=6
1420N    DNIA=1
1430N    COAL=4
1440N    NFCREW=Ø
1450N    FLYCRS=2
1460C    MOPHRS=29.1
1470C    OPALRQ=4
1480N    OPDNIA=1
1490N    CALRAC=1
1500N    CREWNF=Ø
1510N    CREWFL=6
1520L    OPCAVL.K=MAX((OPCAVL.J+(DT)(DNIAAC.JK+
1521X    CALRAC.JK+CRNFAC.JK+CRFLAC.JK-
1530X    OPDNIA.JK-OPCOAL.JK-CREWNF.JK-CREWFL.JK)),Ø)
1540L    DNIA.K=MAX((DNIA.J+(DT)(OPDNIA.JK-
1541X    DNIAAC.JK)),Ø)
1550R    OPDNIA.KL=NORMRN(.Ø6,.ØØ1)*OPCAVL.K
1560R    DNIAAC.KL=DELAY1(OPDNIA.JK,DEDNIA)
1570L    COAL.K=MAX((COAL.J+(DT)(OPCOAL.JK-
1571X    CALRAC.JK)),Ø)
1580A    OPALRT.K=MAX((OPCAVL.K-OPDNIA.K),Ø)
1590R    OPCOAL.KL=MIN((MIN((OPALRQ-COAL.K+
```

```
1591X    CALRAC.JK),OPALRT.K)),ACAVLA.K)
16ØØR    CALRAC.KL=DELAY3(OPCOAL.JK,DECALR)
161ØA    OPDNIF.K=MAX((MIN(((NORMRN(.Ø5,.Ø2))*
1611X    (1+(STEP(EXDNIF,STADNF
162ØX    )-STEP(EXDNI.K,STPDNF)))),1)*
1621X    (OPALRT.K-OPCOAL.JK+CALRAC.JK)),
163ØX    Ø)
164ØA    OPAVLF.K=MAX((OPCAVL.K-OPCOAL.JK-OPDNIF.K-
1641X    OPDNIA.JK),Ø)
165ØA    OPLIMH.K=MOPHRS*OPAVLF.K
166ØA    HRSACT.K=MIN(HRSPO.K,OPLIMH.K)
167ØA    OPSORL.K=TABHL(OPSOR,RDIFFU.JK,Ø,36Ø,9Ø)
168ØT    OPSOR=6/7/8/9/1Ø
169ØA    OPSORT.K=HRSACT.K/OPSORL.K
17ØØA    MXSORT.K=TABHL(MXSOR,OPSORT.K,Ø,13,13)
171ØT    MXSOR=Ø/13
172ØA    MXSORL.K=CLIP(Ø,(HRSACT.K/((MXSORT.K)+
1721X    (1E-2Ø))),Ø,MXSORT.K)
173ØA    UREQOP.K=CLIP(Ø,((OPSORT.K/((MXSORT.K)+
1731X    (1E-2Ø)))*MNUTIL),
174ØX    Ø,MXSORT.K)
175ØA    MXFAC.K=TABHL(MXFA,UREQOP.K,Ø,.8,.1)
176ØNOTE    6Ø% UTIL =.1 PRESS. FACTOR
177ØT    MXFA=.1/.1/.1/.1/.1/.1/.1/.5/1
178ØA    OPSFAC.K=TABHL(OPSFA,RDIFFU.JK,Ø,36Ø,9Ø)
179ØNOTE    36Ø = ENTIRE CREWFORCE 4 DAYS BEHIND
18ØØT    OPSFA=.1/.3/.7/.9/1
181ØA    NETFAC.K=OPSFAC.K+MXFAC.K
182ØA    OPFACR.K=OPSFAC.K/NETFAC.K
183ØA    MXFACR.K=MXFAC.K/NETFAC.K
184ØA    DESHRS.K=(OPFACR.K*OPSORL.K)+
1841X    (MXFACR.K*MXSORL.K)
185ØA    SORTIE.K=HRSACT.K/DESHRS.K
186ØA    SORTNF.K=(HRLRTR.K*SORTIE.K)-
1861X    (OVRRTR.K*SORTIE.K)
187ØA    SORTFL.K=SORTIE.K-SORTNF.K
188ØA    ACTSPA.K=CLIP(Ø,(SORTFL.K/((SCHAFL.K)+
1881X    (1E-2Ø))),Ø,SCHAFL.K)
189ØA    DNC.K=MAX((OPAVLF.K-(SORTIE.K/CRSORT)),Ø)
19ØØA    CRSCHF.K=OPAVLF.K-DNC.K
191ØL    NFCREW.K=MAX((NFCREW.J+(DT)(CREWNF.JK-
1911X    CRNFAC.JK)),Ø)
192ØA    CREWN.K=MAX((CRSCHF.K-SORTFL.K),Ø)
193ØR    CREWNF.KL=CREWN.K
194ØR    CRNFAC.KL=MAX((DELAY3(CREWN.K,DEOPNF)),Ø)
195ØL    FLYCRS.K=MAX((FLYCRS.J+(DT)(CREWFL.JK-
1951X    CRFLAC.JK)),Ø)
196ØA    CREWF.K=CRSCHF.K-CREWN.K
```

```
1970R    CREWFL.KL=CREWF.K
1980R    CRFLAC.KL=DELAY3(CREWF.K,((CLIP(1,
1990X    (SORTFL.K/((CREWF.K)+(1E-2Ø))),
1991X    Ø,CREWF.K))*DECSCF))
2ØØØA    OCAGTG.K=DNC.K+COAL.K+OPDNIF.K+(.95*DNIA.K)
2Ø1ØNOTE
2Ø2ØNOTE    END OPS CREW AVAIL FOR FLY TNG SECTOR
2Ø3ØNOTE
2Ø4ØNOTE    BEGIN FLY TRAINING REQMNTS SECTOR
2Ø5ØNOTE
2Ø6ØN    RQHRBH=Ø
2Ø7ØN    FRQREM=5865   REFLECTS 15 CREWS ASSIGNED
2Ø8ØN    RDIFF=4Ø
2Ø9ØN    RDIFFU=4Ø
21ØØA    BASRQS.K=26+STEP(2,13.99)
211ØNOTE    BASRQS ARE RQMTS PER 6 HR BASE-SORTIE
212ØC    BDESHR=6.Ø
213ØC    FRQMNT=5865
214ØA    RQASG.K=PULSE(FRQMNT,13.99,13)
215ØL    FRQREM.K=MAX((CLIP((FRQREM.J+RQASG.J-(DT)*
2151X    (RQUSRT.JK)),
216ØX    FRQMNT,FRQMNT,(FRQREM.J+RQASG.J-(DT)*
2161X    (RQUSRT.JK)))),Ø)
217ØA    RQX.K=RAMP(((Ø-FRQMNT)/13),Ø)
218ØA    DERQRM.K=(FRQMNT+STEP(FRQMNT,14)+
219ØX    STEP(FRQMNT,27)+STEP(FRQMNT,4Ø))+RQX.K
22ØØA    RDIFF.K=MAX((FRQREM.K-DERQRM.K),Ø)
221ØA    SCHMEM.K=TABHL(SCHME,WKSREM.K,Ø,13,1)
222ØT    SCHME=.Ø2/.265/.51/.755/1/2.5/4/4.571/
223ØX    5.14/5.714/6.286/6.857/7.429/8
224ØR    RDIFFU.KL=SMOOTH(RDIFF.K,SCHMEM.K)
225ØA    EXRQBH.K=MAX(((FRQREM.K-DERQRM.K)-36Ø),Ø)
226ØA    RQHRBH.K=RDIFF.JK/BASRQS.K   ACTUAL BEHIND
227ØA    OVRBAS.K=DESHRS.K/BDESHR
228ØA    RQSCH.K=OVRBAS.K*BASRQS.K*SORTIE.K
229ØA    RQOVR.K=OVRRTR.K*RQSCH.K
23ØØA    RQNAC.K=(MAX((NORMRN((HRLRTC.K),.12)),
231ØX    HRLRTR.K))*RQSCH.K
232ØR    RQUSRT.KL=MIN(FRQREM.K,(RQSCH.K+RQOVR.K-
2321X    RQNAC.K))
233ØNOTE
234ØNOTE    END FLY TRAINING REQMNTS SECTOR
235ØNOTE
236ØPRINT    FHRRMN,WKSREM,HRSDES,HRSPO,HRSPOS,
2361X    HRLRTR,HRSSNA,
237ØX    HRSOVR,HRSFLN,ACAVAL,ACRQMX,INMX,RQMXAC,ACONA,
238ØX    ACON,ALRTAC,ACAVLF,DIFF,DEHRMN,MAXHR,MAXHRS,
2381X    ACTMHR,EXRQHB,
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2390X    HRAVLF,DNA,ACSCHF,ACSNAF,NOFLAC,ACSNA,SCHACF,
2400X    FLYAC,ACFLAC,OPDNIA,DNIA,DNIAAC,OPCAVL,OPALRT,
2410X    OPCOAL,COAL,CALRAC,OPDNIF,OPAVLF,OPLIMH,HRSACT,
2420X    OPSORL,OPSORT,MXSORL,MXSORT,SCHSPA,ACTSPA,
2430X    DESHRS,SORTIE,SORTNF,SORTFL,DNC,CRSCHF,CREWNF,
2440X    NFCREW.CRNFAC,CREWFL,FLYCRS,CRFLAC,OCAGTG,
2450X    FRQREM,DERQRM,RDIFF,RDIFFU,RQHRBH,RQSCH,
2460X    RQOVR,RQNAC,RQUSRT,OVRBAS,EXRQBH,
2470X    UREQOP,MXFAC,OPSFAC,NETFAC,OPFACR,MXFACR,
2480X    BRKRTE,
2490PLOT   HRLRTR/RDIFFU/RDIFF
2500PLOT   ACTMHR/HRAVLF,HRSACT
2510PLOT   DESHRS/SORTIE/OPFACR,MXFACR
2520PLOT   ACAVAL/INMX/ACON
2530PLOT   ACAVLF/ACSCHF/FLYAC
2540PLOT   FHRRMN,DEHRMN
2550PLOT   OPSORL,MXSORL,DESHRS
2560PLOT   OPSORT,MXSORT,SORTIE
2570PLOT   OPFACR,MXFACR/UREQOP
2580PLOT   SCHSPA/ACTMHR/BRKRTE
2590PLOT   FRQREM,DERQRM/RQSCH
2600PLOT   RDIFFU/OVRBAS/RDIFF/EXRQBH
2610PLOT   OPCAVL/COAL/OPAVLF/FLYCRS
2620SPEC   DT=.01/LENGTH=26/PRTPER=1/PLTPER=.25
2630RUN   LORING
```

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